Chapter 13
HIGH ALTITUDE WEATHER

Many general aviation as well as air carrier and military aircraft routinely fly the upper troposphere and lower stratosphere. Weather phenomena of these higher altitudes include the tropopause, the jet stream, cirrus clouds, clear air turbulence, condensation trails, high altitude "haze" layers, and canopy static. This chapter explains these phenomena along with the high altitude aspects of the more common icing and thunderstorm hazards.

THE TROPOPAUSE

Why is the high altitude pilot interested in the tropopause? Temperature and wind vary greatly in the vicinity of the tropopause affecting efficiency, comfort, and safety of flight. Maximum winds generally occur at levels near the tropopause. These strong winds create narrow zones of wind shear which often generate hazardous turbulence. Preflight knowledge of temperature, wind, and wind shear is important to flight planning.

In chapter 1, we learned that the tropopause is a thin layer forming the boundary between the troposphere and stratosphere. Height of the tropopause varies from about 65,000 feet over the Equator to 20,000 feet or lower over the poles. The tropopause is not continuous but generally descends step-wise from the Equator to the poles. These steps occur as "breaks." Figure 123 is a cross section of the troposphere and lower stratosphere showing the tropopause and associated features. Note the break between the tropical and the polar tropopauses.

An abrupt change in temperature lapse rate characterizes the tropopause. Note in figure 123 how temperature above the tropical tropopause increases with height and how over the polar tropopause, temperature remains almost constant with height.

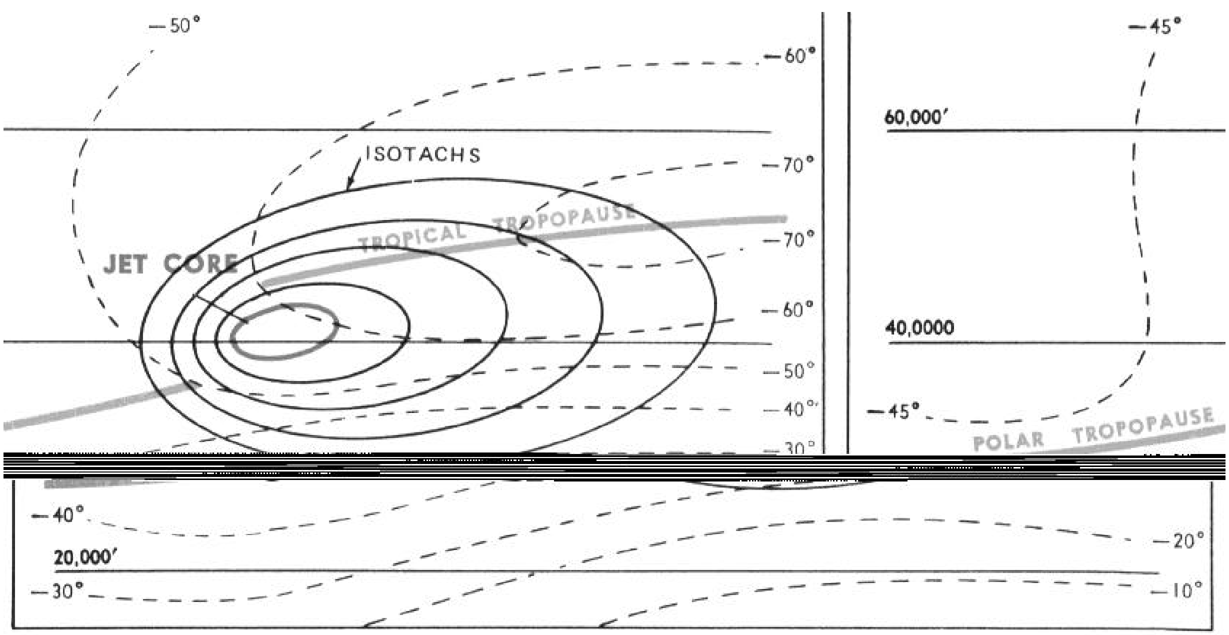


FIGURE 123. A cross section of the upper troposphere and lower stratosphere showing the tropopause and associated features. Note the "break" between the high tropical and the lower polar tropopause. Maximum winds occur in the vicinity of this break.

THE JET STREAM

Diagrammed in figure 124, the jet stream is a narrow, shallow, meandering river of maximum winds extending around the globe in a wavelike pattern. A second jet stream is not uncommon, and three at one time are not unknown. A jet may be as far south as the northern Tropics. A jet in midlatitudes generally is stronger than one in or near the Tropics. The jet stream typically occurs in a break in the tropopause as shown in figure 123. Therefore, a jet stream occurs in an area of intensified temperature gradients characteristic of the break.

The concentrated winds, by arbitrary definition, must be 50 knots or greater to classify as a jet

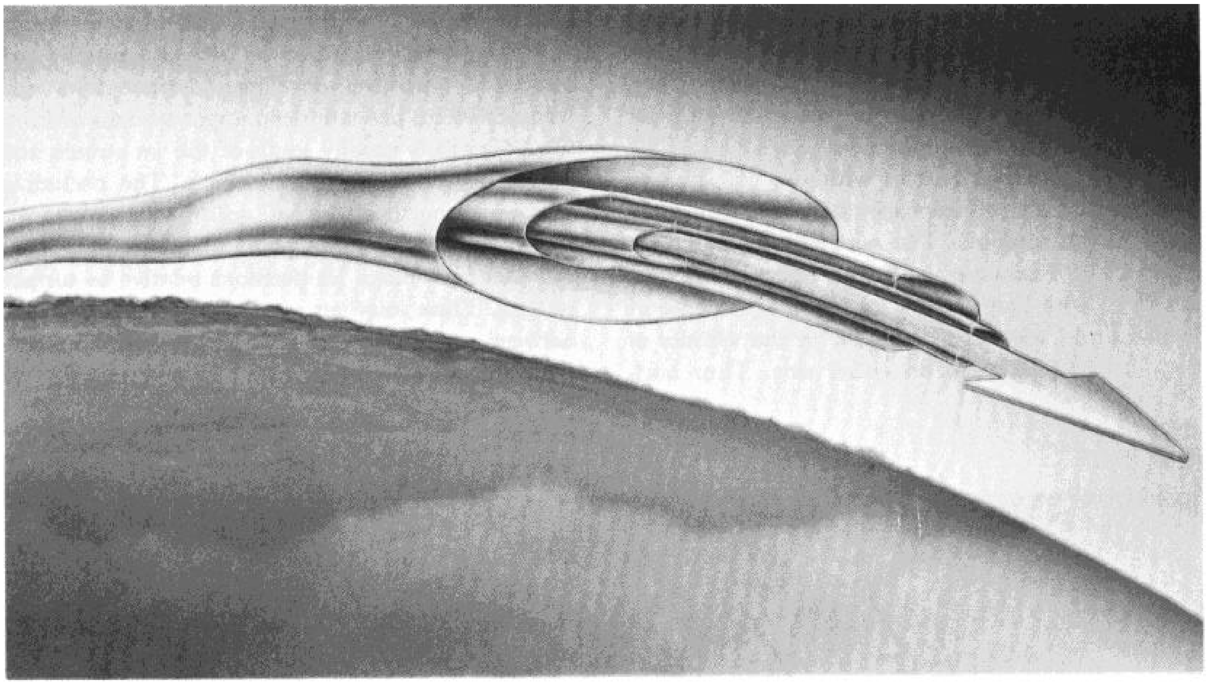


FIGURE 124. Artist's concept of the jet stream. Broad arrow shows direction of wind.

stream. The jet maximum is not constant; rather, it is broken into segments, shaped something like a boomerang as diagrammed in figure 125.

Jet stream segments move with pressure ridges and troughs in the upper atmosphere. In general they travel faster than pressure systems, and maximum wind speed varies as the segments progress through the systems. In midlatitude, wind speed in the jet stream averages considerably stronger in winter than in summer. Also the jet shifts farther south in winter than in summer.

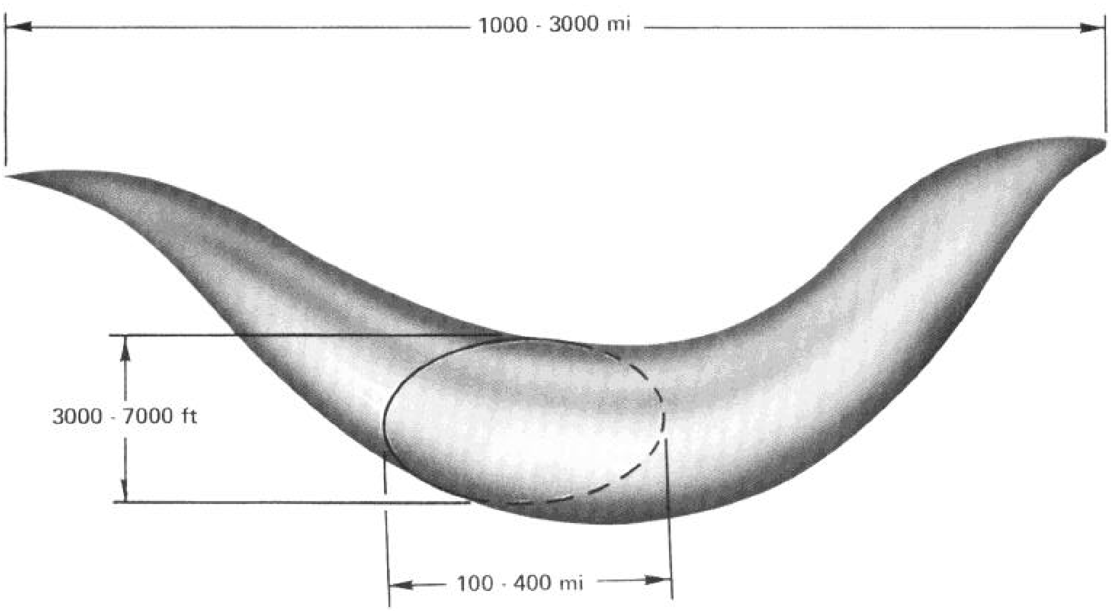


FIGURE 125. A jet stream segment.

In figure 123 note how wind speed decreases outward from the jet core. Note also that the rate of decrease of wind speed is considerably greater on the polar side than on the equatorial side; hence, the magnitude of wind shear is greater on the polar side than on the equatorial side.

Figure 126 shows a map with two jet streams. The paths of the jets approximately conform to the shape of the contours. The northerly jet has three segments of maximum wind, and the southerly one has two. Note how spacing of the height contours is closer and wind speeds higher in the vicinity of the jets than outward on either side. Thus horizontal wind shear is evident on both sides of the jet and is greatest near the maximum wind segments.

Strong, long-trajectory jet streams usually are associated with well-developed surface lows and frontal systems beneath deep upper troughs or lows. Cyclogenesis is usually south of the jet stream and moves nearer as the low deepens. The occluding low moves north of the jet, and the jet crosses the frontal system near the point of occlusion. Figure 127 diagrams mean jet positions relative to surface systems. These long jets mark high level boundaries between warm and cold air and are favored places for cirriform cloudiness.

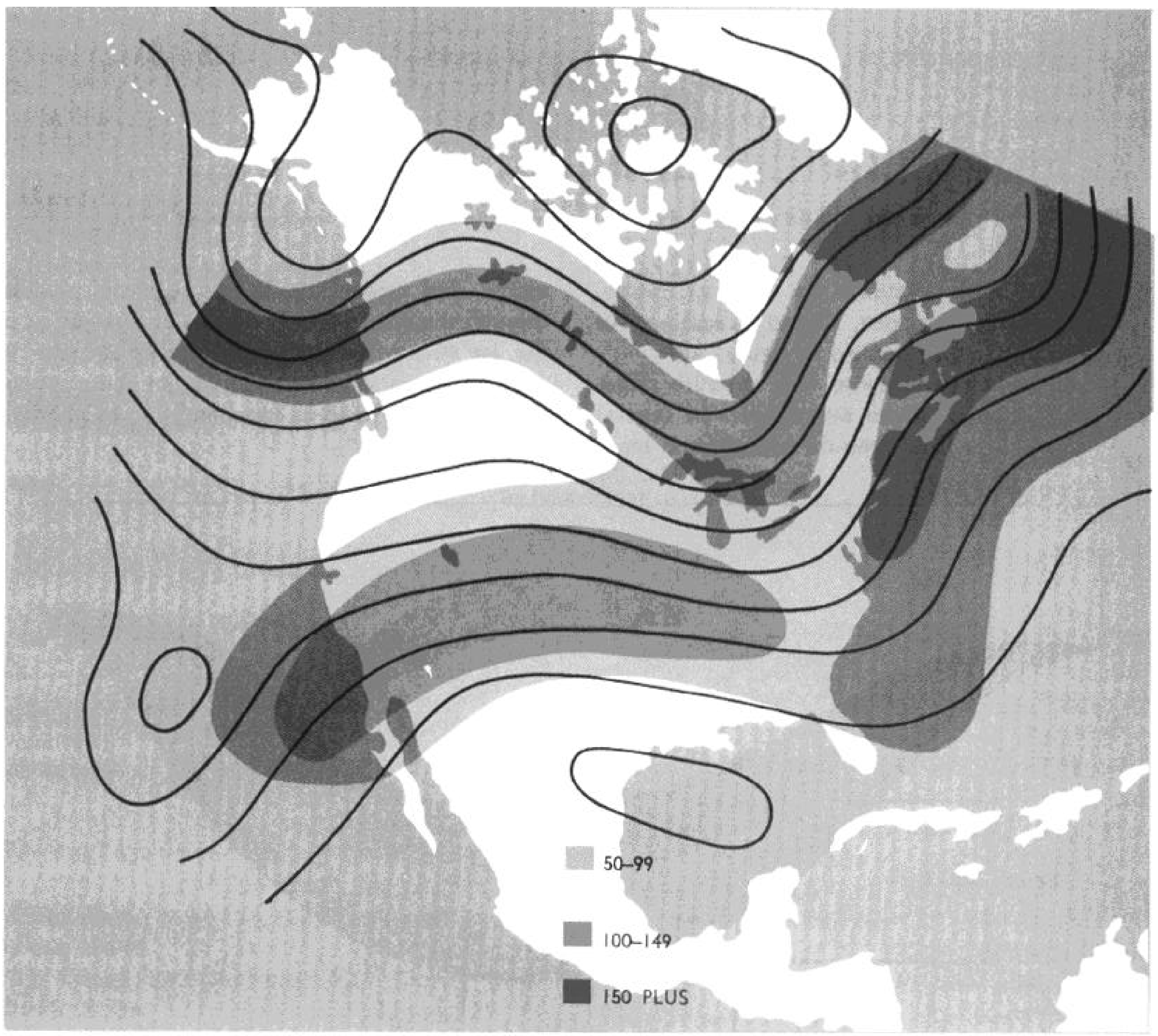


FIGURE 126. Multiple jet streams. Note the "segments" of maximum winds embedded in the general pattern. Turbulence usually is greatest on the polar sides of these maxima.

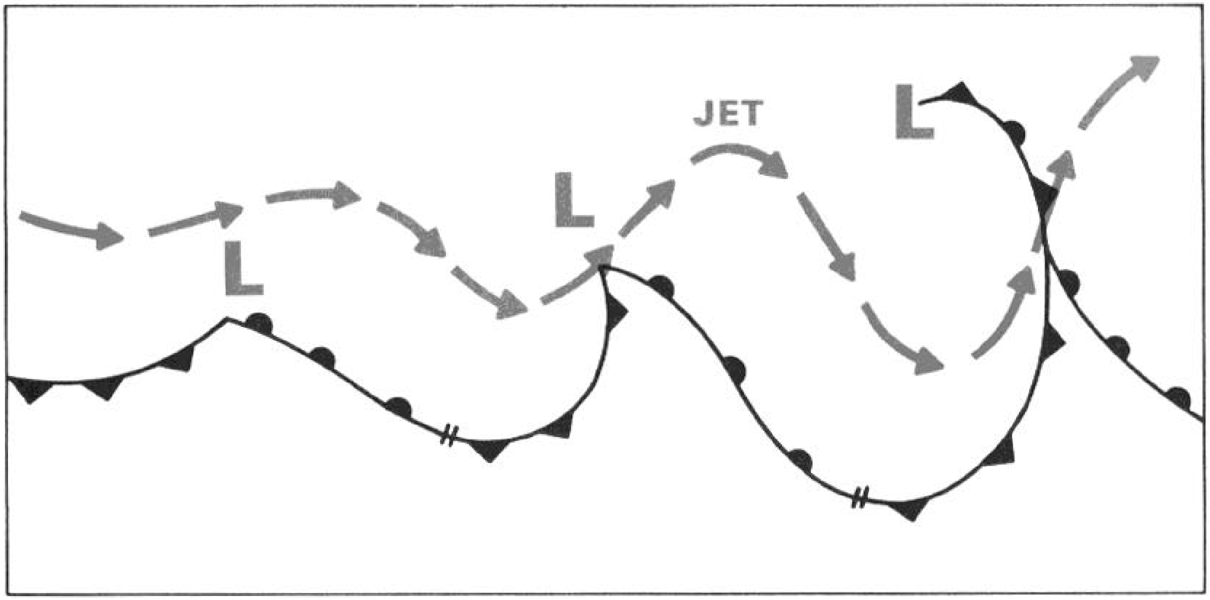


FIGURE 127. Mean jet positions relative to surface systems. Cyclogenesis (development) of a surface low usually is south of the jet as shown on the left. The deepening low moves nearer the jet, center. As it occludes, the low moves north of the jet, right; the jet crosses the frontal system near the point of occlusion.

CIRRUS CLOUDS

Air travels in a "corkscrew" path around the jet core with upward motion on the equatorial side. Therefore, when high level moisture is available, cirriform clouds form on the equatorial side of the jet. Jet stream cloudiness can form independently of well-defined pressure systems. Such cloudiness ranges primarily from scattered to broken coverage in shallow layers or streaks. Their sometimes fish hook and streamlined, wind-swept appearance always indicates very strong upper wind usually quite far from developing or intense weather systems.

The most dense cirriform clouds occur with well-defined systems. They appear in broad bands. Cloudiness is rather dense in an upper trough, thickens downstream, and becomes most dense at the crest of the downwind ridge. The clouds taper off after passing the ridge crest into the area of descending air. The poleward boundary of the cirrus band often is quite abrupt and frequently casts a shadow on lower clouds, especially in an occluded frontal system. Figure 128a is a satellite photograph showing a cirrus band casting a shadow on lower clouds. Figure 1 28b is an infrared photo of the same system; the light shade of the cirrus band indicates cold temperatures while warmer low clouds are the darker shades.

The upper limit of dense, banded cirrus is near the tropopause; a band may be either a single layer or multiple layers 10,000 to 12,000 feet thick. Dense, jet stream cirriform cloudiness is most prevalent along midlatitude and polar jets. However, a cirrus band usually forms along the subtropical jet in winter when a deep upper trough plunges southward into the Tropics.

Cirrus clouds, in themselves, have little effect on aircraft. However, dense, continuous coverage requires a pilot's constant reference to instruments; most pilots find this more tiring than flying with a visual horizon even though IFR.

A more important aspect of the jet stream cirrus shield is its association with turbulence. Extensive cirrus cloudiness often occurs with deepening surface and upper lows; and these deepening systems produce the greatest turbulence.

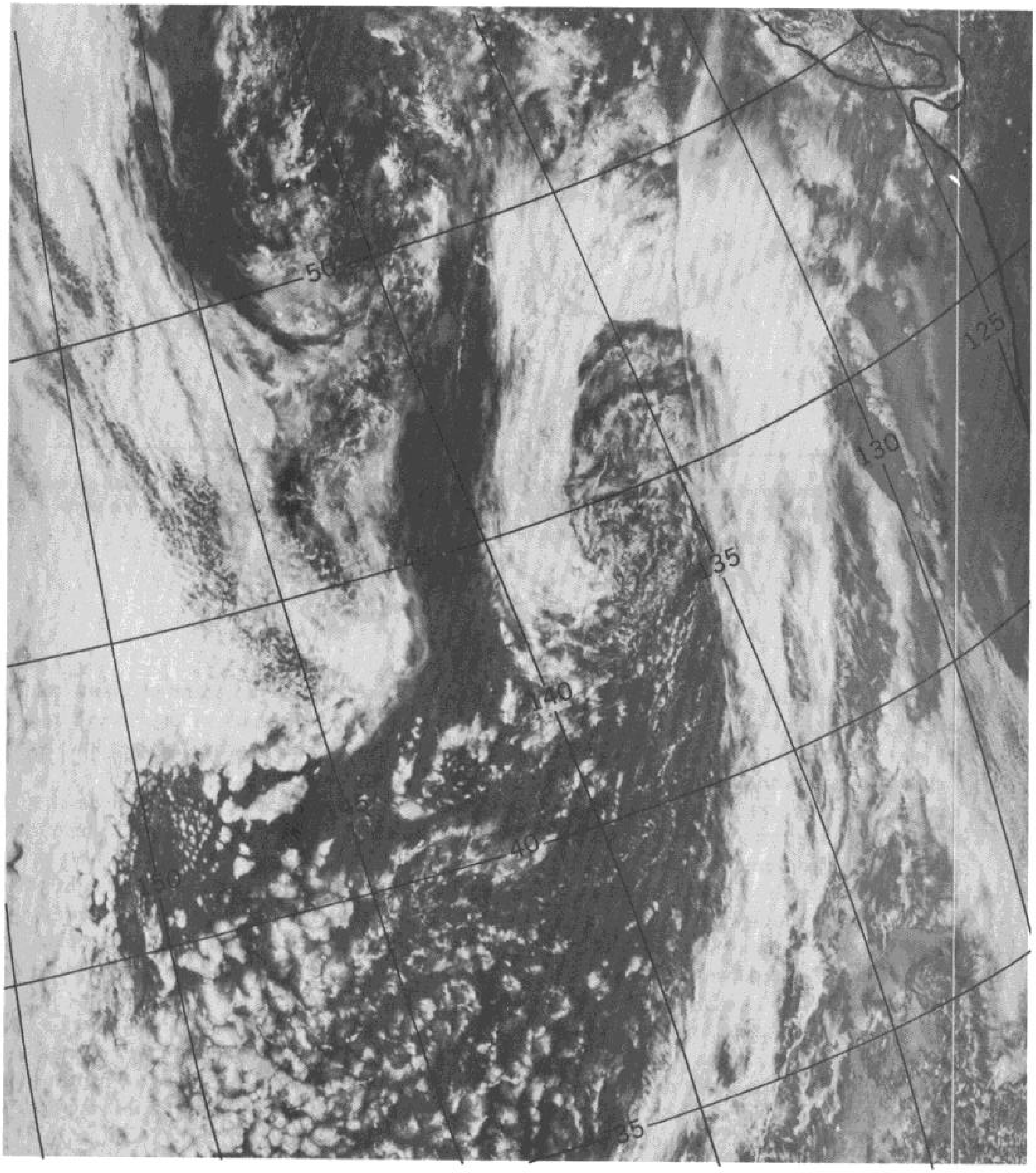


FIGURE 128a. Satellite photograph of an occluded system centered at about 44° N and 137° W. Here, the jet extends south-southwest to north-northeast along the polar (more westerly) boundary of the cirrus band from 35° N, 141° W through 43° N, 135° W to 51° N, 130° W. Shadow of the cirrus band is clearly evident as a narrow dark line from 45° N, 134.5° W to 49° N, 132° W.

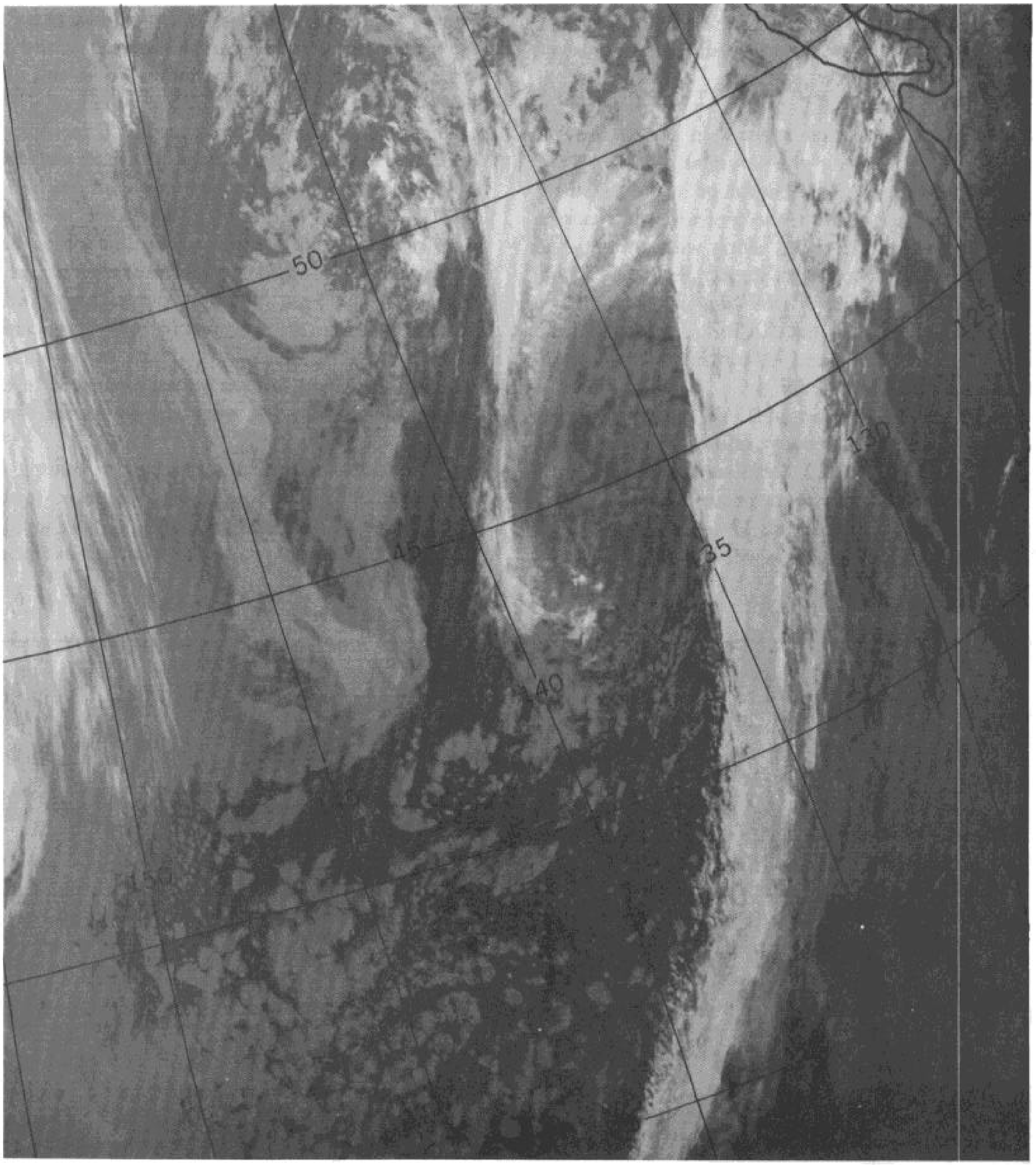


FIGURE 128b. Infrared photograph of the system shown in figure 128a. The warmer the radiating surface, the darker the shade; the cold cirrus appears nearly white. Infrared clearly distinguishes the banded jet stream cirrus from other cirrus and lower clouds.

CLEAR AIR TURBULENCE

Clear air turbulence (CAT) implies turbulence devoid of clouds. However, we commonly reserve the term for high level wind shear turbulence, even when in cirrus clouds.

Cold outbreaks colliding with warm air from the south intensify weather systems in the vicinity of the jet stream along the boundary between the cold and warm air. CAT develops in the turbulent energy exchange between the contrasting air masses. Cold and warm advection along with strong wind shears develop near the jet stream, especially where curvature of the jet stream sharply increases in deepening upper troughs. CAT is most pronounced in winter when temperature contrast is greatest between cold and warm air.

A preferred location of CAT is in an upper trough on the cold (polar) side of the jet stream. Another frequent CAT location, shown in figure 129, is along the jet stream north and northeast of a rapidly deepening surface low.

Even in the absence of a well-defined jet stream, CAT often is experienced in wind shears associated with sharply curved contours of strong lows, troughs, and ridges aloft, and in areas of strong, cold or warm air advection. Also mountain waves can create CAT. Mountain wave CAT may extend from the mountain crests to as high as 5,000 feet above the tropopause, and can range 100 miles or more downstream from the mountains.

CAT can be encountered where there seems to be no reason for its occurrence. Strong winds may carry a turbulent volume of air away from its source region. Turbulence intensity diminishes downstream, but some turbulence still may be encountered where it normally would not be expected. CAT forecast areas are sometimes elongated to indicate probable turbulence drifting downwind from the main source region.

A forecast of turbulence specifies a volume of airspace which is quite small when compared to the total volume of airspace used by aviation, but is relatively large compared to the localized extent of

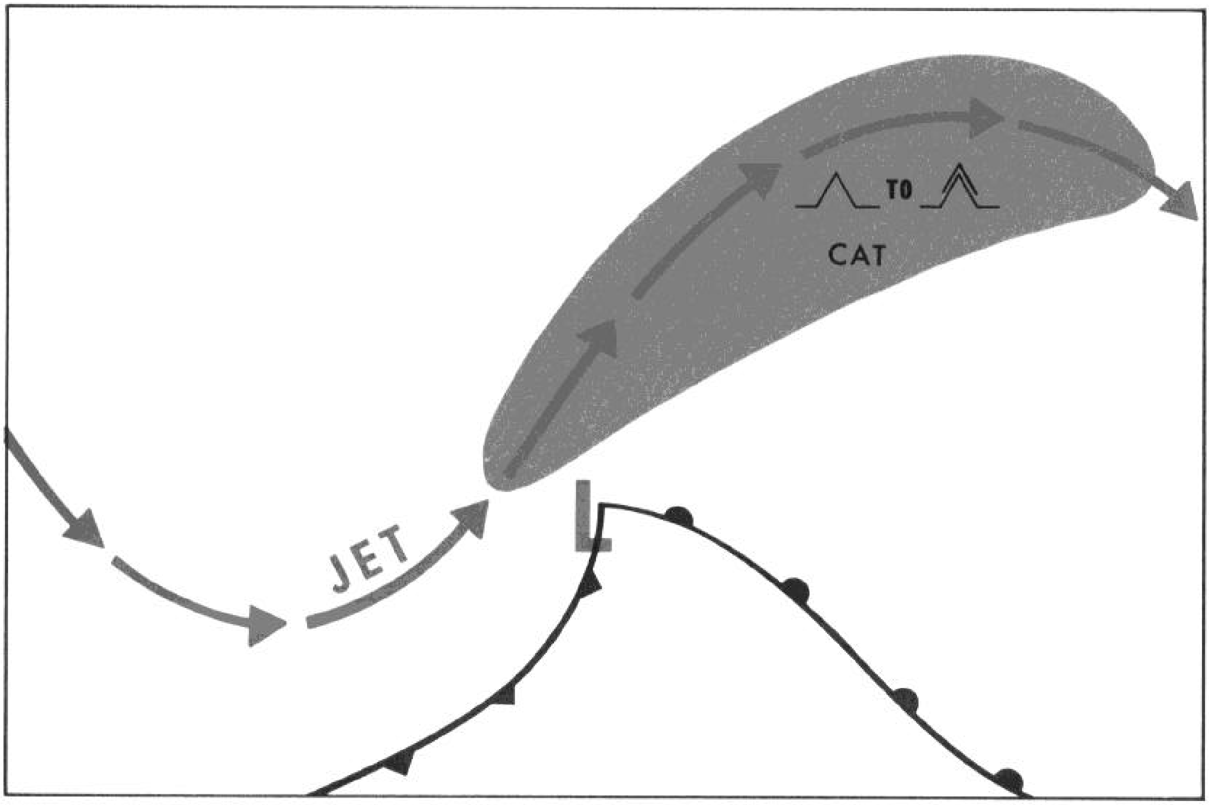


FIGURE 129. A frequent CAT location is along the jet stream north and northeast of a rapidly deepening surface low.

the hazard. Since turbulence in the forecast volume is patchy, you can expect to encounter it only intermittently and possibly not at all. A flight through forecast turbulence, on the average, encounters only light and annoying turbulence 10 to 15 percent of the time; about 2 to 3 percent of the time there is a need to have all objects secured; the pilot experiences control problems only about two-tenths of I percent of the time—odds of this genuinely hazardous turbulence are about 1 in 500.

Look again at figure 126. Where are the most probable areas of CAT ? Turbulence would be greatest near the windspeed maxima, usually on the polar sides where there is a combination of strong wind shear, curvature in the flow, and cold air advection. These areas would be to the northwest of Vancouver Island, from north of the Great **Lakes** to east of James Bay and over the Atlantic east of Newfoundland. Also, turbulence in the form of mountain waves is probable in the vicinity of the jet stream from southern California across the Rockies into the Central Plains.

In flight planning, use upper air charts and forecasts to locate the jet stream, wind shears, and areas of most probable turbulence. AVIATION WEATHER SERVICES (AC 00-45) explains in detail how to obtain these parameters. If impractical to avoid completely an area of forecast turbulence, proceed with caution. You will do well to avoid areas where vertical shear exceeds 6 knots per 1,000 feet or horizontal shear exceeds 40 knots per 150 miles.

What can you do if you get into CAT rougher than you care to fly? If near the jet core, you could climb or descend a few thousand feet or you could move farther from the jet core. If caught in CAT not associated with the jet stream, your best bet is to change altitude since you have no positive way of knowing in which direction the strongest shear lies. Pilot reports from other flights, when available, are helpful.

Flight maneuvers increase stresses on the aircraft as does turbulence. The increased stresses are cumulative when the aircraft maneuvers in turbulence. Maneuver gently when in turbulence to minimize stress. The patchy nature of CAT makes current pilot reports extremely helpful to observers, briefers, forecasters, air traffic controllers, and, most important, to your fellow pilots. Always, if at all possible, make inflight weather reports of CAT or other turbulence encounters; negative reports also help when no CAT is experienced where it normally might be expected.

CONDENSATION TRAILS

A condensation trail, popularly contracted to "contrail," is generally defined as a cloud-like streamer which frequently is generated in the wake of aircraft flying in clear, cold, humid air, figure 130. Two distinct types are observed—exhaust trails and aerodynamic trails. "Distrails," contracted from dissipation trails, are produced differently from exhaust and aerodynamic trails.

EXHAUST CONTRAILS

The exhaust contrail is formed by the addition to the atmosphere of sufficient water vapor from aircraft exhaust gases to cause saturation or supersaturation of the air. Since heat is also added to the atmosphere in the wake of an aircraft, the addition of water vapor must be of such magnitude that it saturates or supersaturates the atmosphere in spite of the added heat. There is evidence to support the idea that the nuclei which are necessary for condensation or sublimation may also be donated to the atmosphere in the exhaust gases of aircraft engines, further aiding contrail formation. These nuclei are relatively large. Recent experiments, however, have revealed that visible exhaust contrails may be prevented by adding very minute nuclei material (dust, for example) to the exhaust. Condensation and sublimation on these smaller nuclei result in contrail particles too small to be visible.

AERODYNAMIC CONTRAILS

In air that is almost saturated, aerodynamic pressure reduction around airfoils, engine nacelles, and propellers cools the air to saturation leaving condensation trails from these components. This type of trail usually is neither as dense nor as persistent as exhaust trails. However, under critical atmospheric conditions, an aerodynamic contrail may trigger the formation and spreading of a deck of cirrus clouds.

Contrails create one problem unique to military operations in that they reveal the location of an aircraft attempting to fly undetected. A more general operational problem is a cirrus layer sometimes induced by the contrail. The induced layer may make necessary the strict use of instruments by a subsequent flight at that altitude.

FIGURE 130. Contrails. The thin contrail is freshly formed by an center of the photograph.

DISSIPATION TRAILS (DISTRAILS)

The term dissipation trail applies to a rift in clouds caused by the heat of exhaust gases from an aircraft flying in a thin cloud layer. The exhaust gases sometimes warm the air to the extent that it is no longer saturated, and the affected part of the cloud evaporates. The cloud must be both thin and relatively warm for a distrail to exist; therefore, they are not common.

HAZE LAYERS

Haze layers not visible from the ground are, at times, of concern at high altitude. These layers are really cirrus clouds with a very low density of ice crystals. Tops of these layers generally are very definite and are at the tropopause. High level haze occurs in stagnant air; it is rare in fresh outbreaks of cold polar air. Cirrus haze is common in Arctic winter. Sometimes ice crystals restrict visibility from the surface to the tropopause.

Visibility in the haze sometimes may be near zero, especially when one is facing the sun. To avoid the poor visibility, climb into the lower stratosphere or descend below the haze. This change may be several thousand feet.

CANOPY STATIC

Canopy static, similar to the precipitation static sometimes encountered at lower levels, is produced by particles brushing against plastic-covered aircraft surfaces. The discharge of static electricity results in a noisy disturbance that interferes with radio reception. Discharges can occur in such rapid succession that interference seems to be continuous. Since dust and ice crystals in cirrus clouds are the primary producers of canopy static, usually you may eliminate it by changing altitude.

ICING

Although icing at high altitude is not as common or extreme as at low altitudes, it can occur. It can form quickly on airfoils and exposed parts of jet engines. Structural icing at high altitudes usually is rime, although clear ice is possible.

High altitude icing generally forms in tops of tall cumulus buildups, anvils, and even in detached cirrus. Clouds over mountains are more likely to contain liquid water than those over more gently sloping terrain because of the added lift of the mountains. Therefore, icing is more likely to occur and to be more hazardous over mountainous areas.

Because ice generally accumulates slowly at high altitudes, anti-icing equipment usually eliminates any serious problems. However, anti-icing systems currently in use are not always adequate. If such is the case, avoid the icing problem by changing altitude or by varying course to remain clear of the clouds. Chapter 10 discusses aircraft icing in more detail.

THUNDERSTORMS

A well-developed thunderstorm may extend upward through the troposphere and penetrate the lower stratosphere. Sometimes the main updraft in a thunderstorm may toss hail out the top or the upper portions of the storm. An aircraft may encounter hail in clear air at a considerable distance from the thunderstorm, especially under the anvil cloud. Turbulence may be encountered in clear air for a considerable distance both above and around a growing thunderstorm.

Thunderstorm avoidance rules given in chapter 11 apply equally at high altitude. When flying in the clear, visually avoid all thunderstorm tops. In a severe thunderstorm situation, avoid tops by at least 20 miles. When you are on instruments, weather avoidance radar assures you of avoiding thunderstorm hazards. If in an area of severe thunderstorms, avoid the most intense echoes by at least 20 miles. Most air carriers now use this distance as the minimum for thunderstorm avoidance.

Chapter 14 ARCTIC WEATHER

The Arctic, strictly speaking, is the region shown in figure 131 which lies north of the Arctic Circle (66~/2° latitude). However, this chapter includes Alaskan weather even though much of Alaska lies south of the Arctic Circle.

Because of the lack of roads over most Arctic areas, aviation is the backbone of transportation between communities. As the economy expands, so will air transportation.

Your most valuable source of information concerning flying the Arctic is the experienced Arctic flyer. To introduce you to Arctic flying weather, this chapter surveys climate, air masses, and fronts of the Arctic; introduces you to some Arctic weather peculiarities; discusses weather hazards in the Arctic; and comments on Arctic flying.

FIGURE 131. The Arctic. The Arctic Circle is at 66½° N latitude.

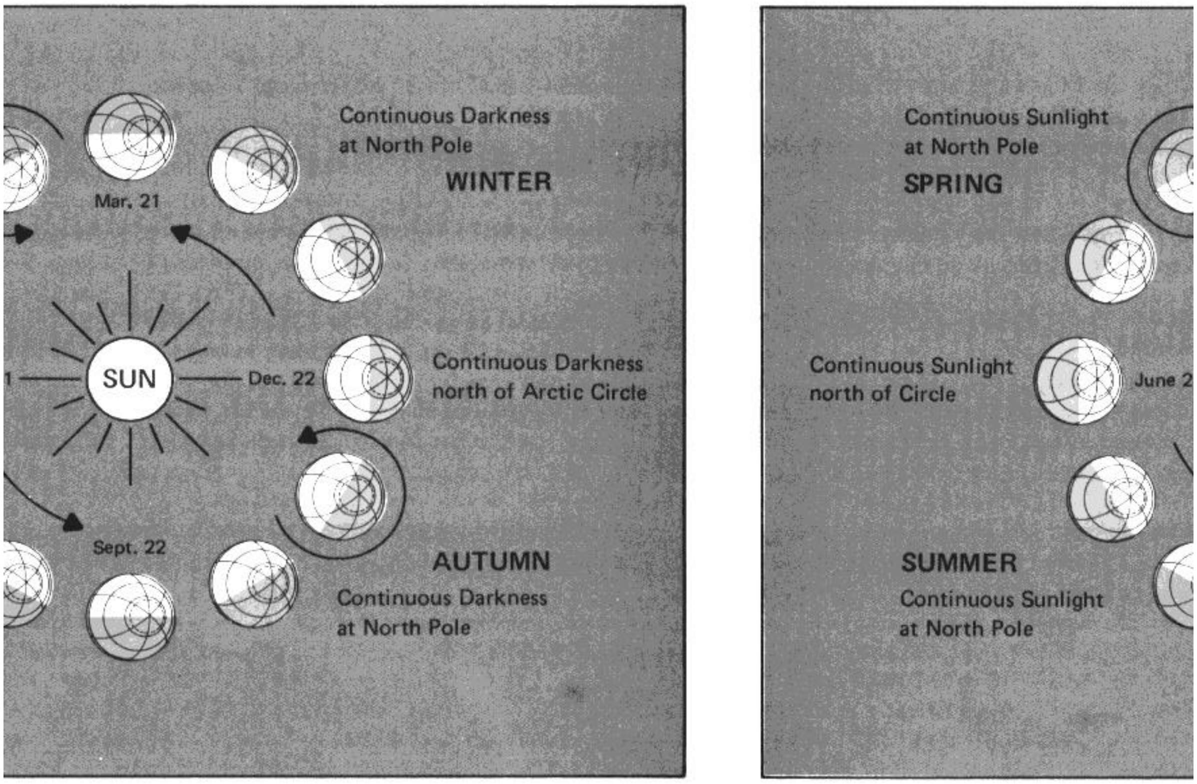
CLIMATE, AIR MASSES, AND FRONTS

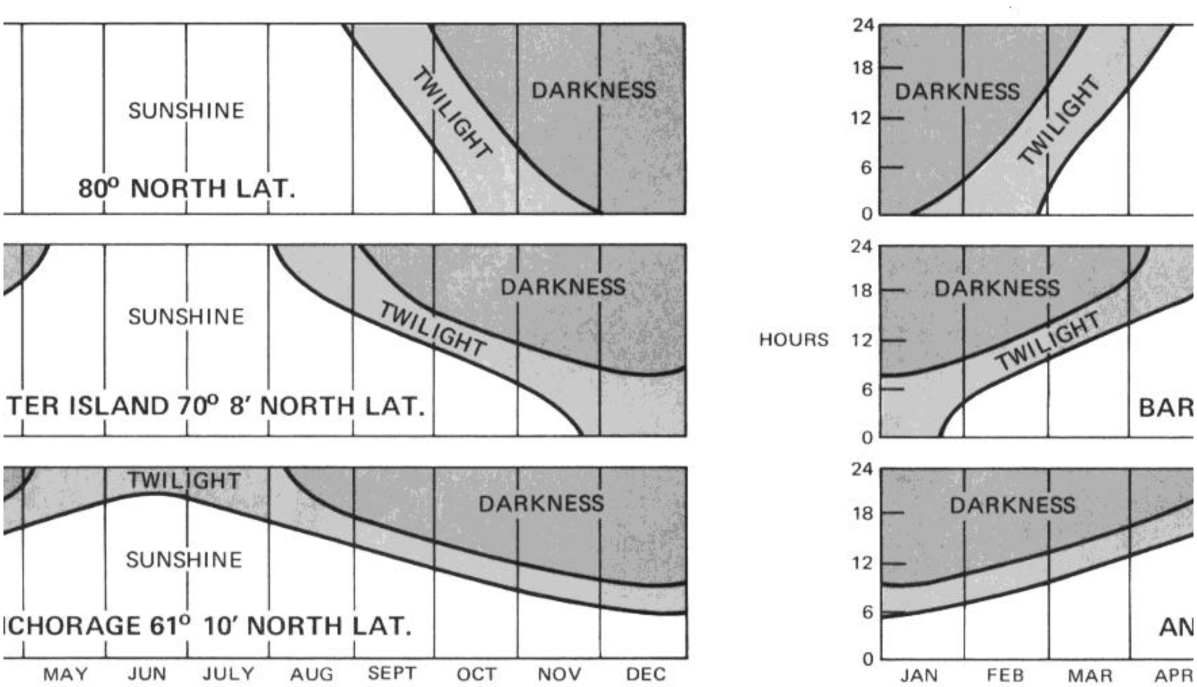
Climate of any region is largely determined by the amount of energy received from the sun; but local characteristics of the area also influence climate .

LONG DAYS AND NIGHTS

A profound seasonal change in length of day and night occurs in the Arctic because of the Earth's tilt and its revolution around the sun. Figure 132 shows that any point north of the Arctic Circle has autumn and winter days when the sun stays all day below the horizon and days in spring and summer with 24 hours of sunshine. The number of these days increases toward the North Pole; there the sun stays below the horizon for 6 months and shines continuously during the other 6 months.

Twilight in the Arctic is prolonged because of the shallow angle of the sun below the horizon. In more northern latitudes, it persists for days when the sun remains just below the horizon. This





phere. The sun shines a full 24 hours on the entire area north of the Arctic
ine decreases until none falls anywhere in the area on December 22. Graphs
l twilight per day at two points north of the Arctic Circle and for Anchorage,
circle.

FIGURE 132. Sunshine in the Northern Hemis
Circle (top) on June 21; the amount of sunsh
(below) show duration of sunshine and nautica
Alaska, at a latitude about 5½° south of the

abundance of twilight often makes visual reference possible at night.

LAND AND WATER

Figure 131 shows the water and land distribution in the Arctic. Arctic mountain ranges are effective barriers to air movement. Large masses of air stagnate over the inland continental areas. Thus, the Arctic continental areas are air mass source regions.

A large portion of the Arctic Ocean is covered throughout the year by a deep layer of ice—the permanent ice pack as shown in figure 133. Even though the ocean is ice-covered through much of the year, the ice and the water below contain more heat than the surrounding cold land, thus moderating the climate to some extent. Oceanic and coastal areas have a milder climate during winter than would be expected and a cool climate in summer. As opposed to large water bodies, large land areas show a more significant seasonal temperature variation.

TEMPERATURE

As one would expect, the Arctic is very cold in winter; but due to local terrain and the movement of pressure systems, occasionally some areas are sur-

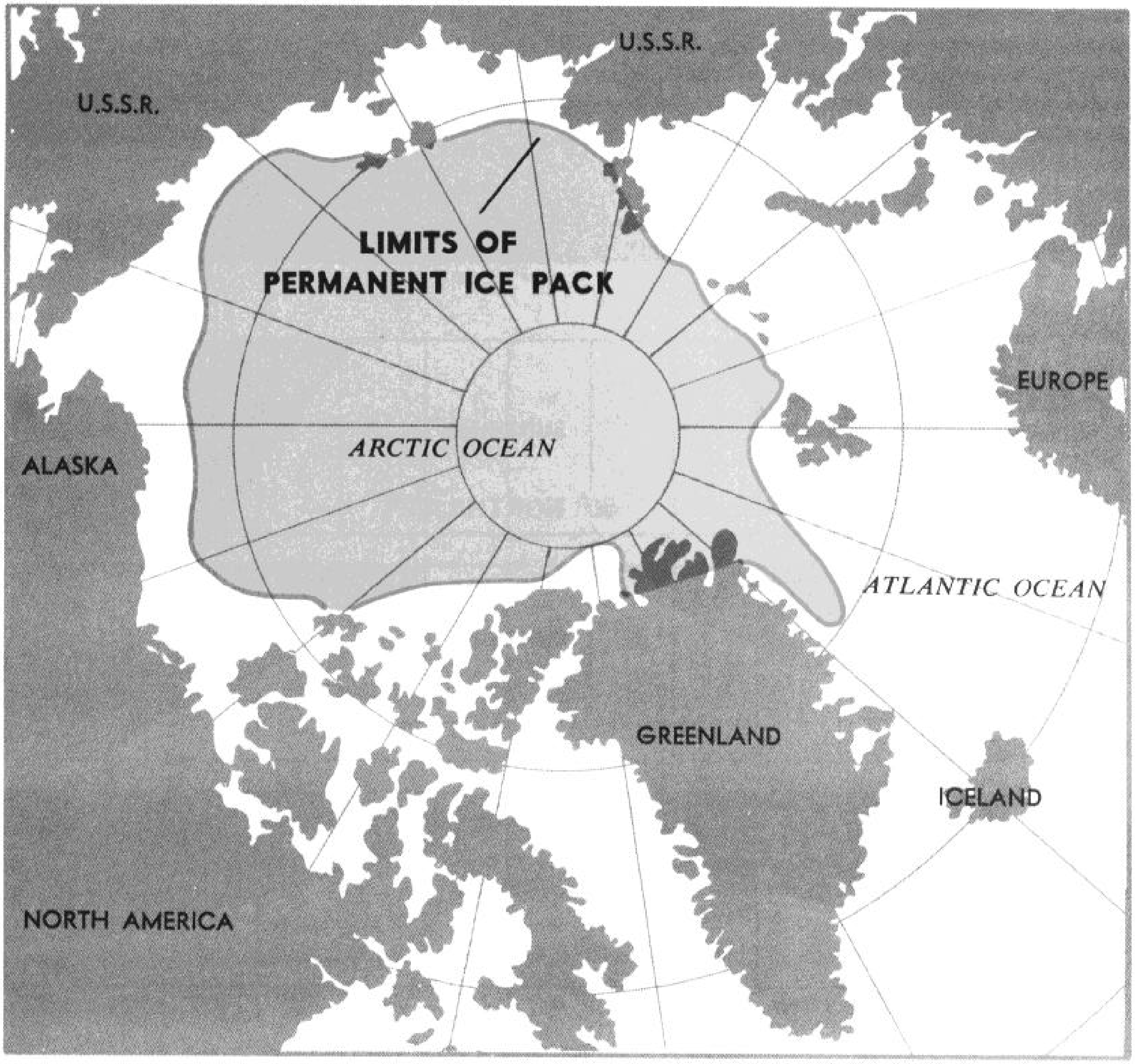


FIGURE 133. The permanent Arctic ice pack.

prisingly warm. During winter, coastal areas average about 20 degrees warmer than the interior. During summer, interior areas are pleasantly warm with many hours of sunshine. Coastal areas have relatively cool short summers due to their proximity to water.

CLOUDS AND PRECIPITATION

Cloudiness over the Arctic is at a minimum during winter reaching a maximum in summer and fall, figure 134. Spring also brings many cloudy days. During summer afternoons, scattered cumulus clouds forming over the interior occasionally grow into thundershowers. These thundershowers, usually circumnavigable, move generally from northeast to southwest in the polar easterlies which is opposite the general movement in midlatitudes.

Precipitation in the Arctic is generally light. Annual amounts over the ice pack and along the coastal areas are only 3 to 7 inches. The interior is somewhat wetter, with annual amounts of 5 to 15 inches. Precipitation falls mostly in the form of

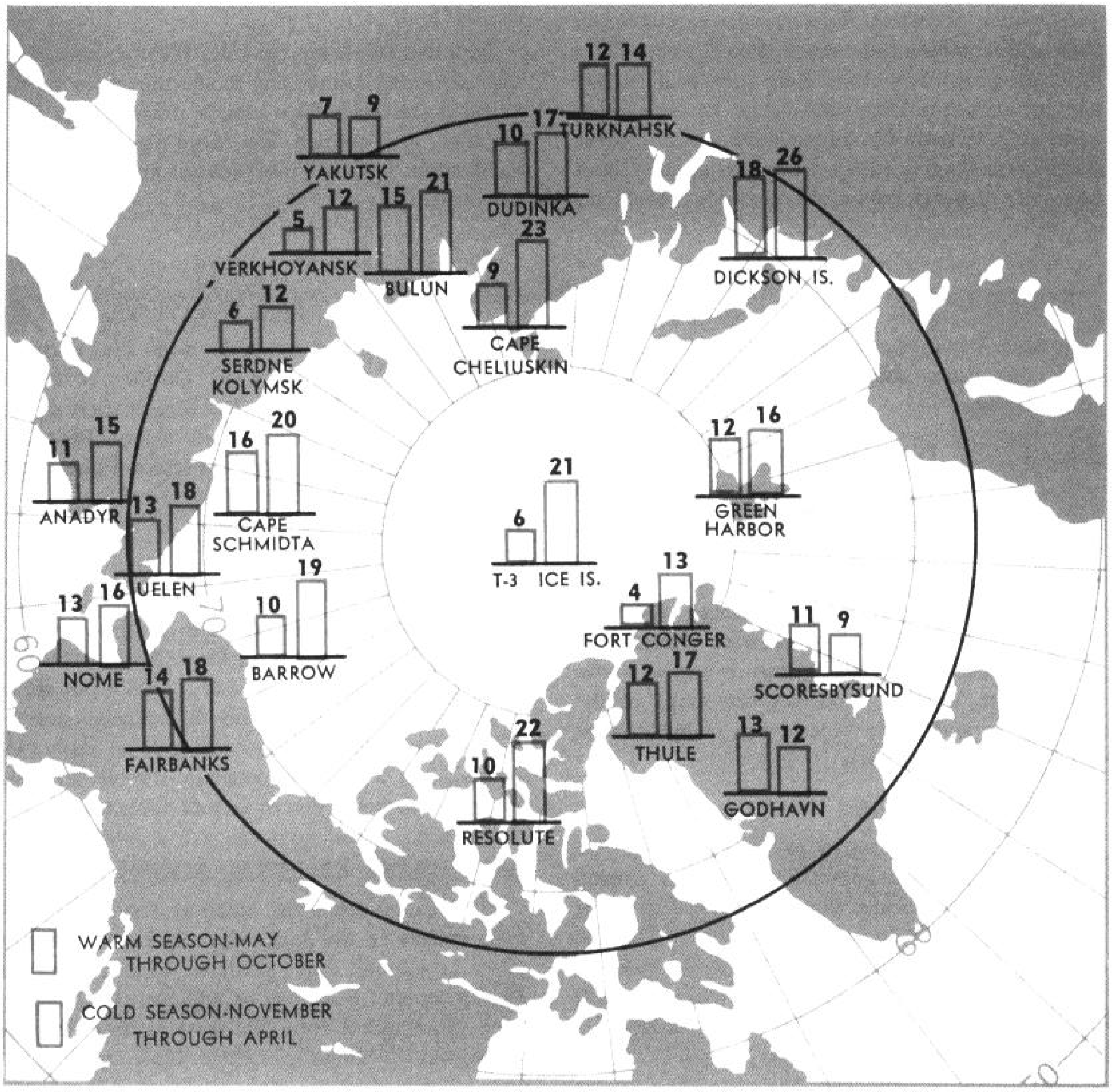


FIGURE 134. Average number of cloudy days per month. Note that most stations show the greatest number of cloudy days in the warmer season.

snow over ice caps and oceanic areas and mostly as summer rain over interior areas.

WIND

Strong winds occur more often along the coasts than elsewhere. The frequency of high winds in coastal areas is greatest in fall and winter. Wind speeds are generally light in the continental interior during the entire year, but are normally at their strongest during summer and fall.

AIR MASSES—WINTER

In winter, air masses form over the expanded ice pack and adjoining snow-covered land areas. These air masses are characterized by very cold surface air, very low humidity, and strong low-level temperature inversions. Occasionally, air from unfrozen ocean areas flows northward over the Arctic. These intrusions of moist, cold air account for most of the infrequent wintertime cloudiness and precipitation in the Arctic.

AIR MASSES—SUMMER

During the summer, the top layer of the Arctic permafrost layer melts leaving very moist ground, and the open water areas of the Polar Basin increase markedly. Thus, the entire area becomes more humid, relatively mild, and semimaritime in character. The largest amount of cloudiness and precipitation occurs inland during the summer months.

FRONTS

Occluded fronts are the rule. Weather conditions with occluded fronts are much the same in the Arctic as elsewhere low clouds, precipitation, poor visibility, and sudden fog formation. Fronts are much more frequent over coastal areas than over the interior.

ARCTIC PECULIARITIES

Several Arctic phenomena are peculiar to that region. At times, they have a direct bearing on Arctic flying.

EFFECTS OF TEMPERATURE INVERSION

The intense low-level inversion over the Arctic during much of the winter causes sound—including people's voices—to carry over extremely long distances. Light rays are bent as they pass at low angles through the inversion. This bending creates an effect known as looming—a form of mirage that causes objects beyond the horizon to appear above the horizon. Mirages distorting the shape of the sun, moon, and other objects are common with these low level inversions.

AURORA BOREALIS

In theory, certain energy particles from the sun strike the Earth's magnetic field and are carried along the lines of force where they tend to lower and converge near the geomagnetic poles. The energy particles then pass through rarefied gases of the outer atmosphere, illuminating them in much the same way as an electrical charge illuminates neon gas in neon signs.

The Aurora Borealis takes place at high altitudes above the Earth's surface and thus has been observed as far south as Florida. However, the highest frequency of observations is over the northern United States and northward. Displays of aurora vary from a faint glow to an illumination of the Earth's surface equal to a full moon. They frequently change shape and form and are also called dancing lights or northern lights.

LIGHT REFLECTION BY SNOW-COVERED SURFACES

Much more light is reflected by snow-covered surfaces than by darker surfaces. Snow often reflects Arctic sunlight sufficiently to blot out shadows, thus markedly decreasing the contrast between objects. Dark distant mountains may be easily recognized, but a crevasse normally directly in view may be undetected due to lack of contrasts.

LIGHT FROM CELESTIAL BODIES

Illumination from the moon and stars is much more intense in the Arctic than in lower latitudes. Pilots have found that light from a half-moon over a snow-covered field may be sufficient for landing. Even illumination from the stars creates visibility far beyond that found elsewhere. Only under heavy overcast skies does the night darkness in the Arctic begin to approach the degree of darkness in lower latitudes.

WEATHER HAZARDS

Weather hazards include visibility restricting phenomena, blowing snow, icing, frost, and lack of contrast—whiteout.

FOG

Fog limits landing and takeoff in the Arctic more than any other visibility restriction. Water-droplet fog is the main hazard to aircraft operations in coastal areas during the summer. Ice fog is the major restriction in winter.

Ice Fog

Ice fog is common in the Arctic. It forms in moist air during extremely cold, calm conditions in winter, occurring often and tending to persist. Effective visibility is reduced much more in ice fog when one is looking toward the sun. Ice fog may be produced both naturally and artificially. Ice fog affecting aviation operations most frequently is produced by the combustion of aircraft fuel in cold air. When the wind is very light and the temperature is about —30° F or colder, ice fog often forms instantaneously in the exhaust gases of automobiles and aircraft. It lasts from as little as a few minutes to days.

Steam Fog

Steam fog, often called "sea smoke," forms in winter when cold, dry air passes from land areas over comparatively warm ocean waters. Moisture evaporates rapidly from the water surface; but since the cold air can hold only a small amount of water vapor, condensation takes place just above the surface of the water and appears as "steam" rising from the ocean. This fog is composed entirely of water droplets that often freeze quickly and fall back into the water as ice particles. Low level turbulence can occur and icing can become hazardous.

Advection Fog

Advection fog, which may be composed either of water droplets or of ice crystals, is most common in winter and is often persistent. Advection fog forms along coastal areas when comparatively warm, moist, oceanic air moves over cold land. If the land areas are hilly or mountainous, lifting of the air results in a combination of low stratus and fog. The stratus and fog quickly diminish inland. Lee sides of islands and mountains usually are free of advection fog because of drying due to compressional heating as the air descends downslope. Icing in advection fog is in the form of rime and may become quite severe.

BLOWING SNOW

Over the frozen Arctic Ocean and along the coastal areas, blowing snow and strong winds are common hazards during autumn and winter. Blowing snow is a greater hazard to flying operations in the Arctic than in midlatitudes because the snow is "dry" and fine and can be picked up easily by light winds. Winds in excess of 8 knots may raise the snow several feet off the ground obliterating objects such as runway markers as illustrated in figure 135. A sudden increase in surface wind may cause an unlimited visibility to drop to near zero in a few minutes. This sudden loss of visibility occurs frequently without warning in the Arctic. Stronger winds sometimes lift blowing snow to heights above 1,000 feet and produce drifts over 30 feet deep.

ICING

Icing is most likely in spring and fall, but is also encountered in winter. During spring and fall, icing may extend to upper levels along frontal zones. While icing is mostly a problem over water and coastal areas, it does exist inland. It occurs typically as rime, but a combination of clear and rime is not unusual in coastal mountains.

FROST

In coastal areas during spring, fall, and winter, heavy frost and rime may form on aircraft parked outside, especially when fog or ice fog is present. This frost should be removed; it reduces lift and is especially hazardous if surrounding terrain requires a rapid rate of climb.

WHITEOUT

"Whiteout" is a visibility restricting phenomenon that occurs in the Arctic when a layer of cloudiness of uniform thickness overlies a snow or ice-covered surface. Parallel rays of the sun are broken up and diffused when passing through the cloud layer so that they strike the snow surface from many angles. The diffused light then reflects back and forth countless times between the snow and the cloud eliminating all shadows. The result is a loss of depth perception. Buildings, people, and dark colored objects appear to float in the air, and the horizon disappears. Low level flight over icecap terrain or landing on snow surfaces becomes dangerous. Disastrous accidents have occurred as a result of whiteouts.

ARCTIC FLYING WEATHER

A great number of pilots who fly Alaska and the Arctic are well seasoned. They are eager to be of help and are your best sources of information. Alaska and the Arctic are sparsely settled with mostly natural landmarks to guide you as illustrated in figure 136. Before flying in the Arctic, be sure to learn all you can about your proposed route.

Generally, flying conditions in the Arctic are

FIGURE 136. A typical frozen landscape of the Arctic.

good when averaged over the entire year; however, areas of Greenland compete with the Aleutians for the world's worst weather. These areas are exceptions.

Whiteouts, in conjunction with overcast skies, often present a serious hazard especially for visual flight. Many mountain peaks are treeless and rounded rather than ragged, making them unusually difficult to distinguish under poor visibility conditions.

OCEANIC AND COASTAL AREAS

In oceanic and coastal areas, predominant hazards change with the seasons. In summer, the main hazard is fog in coastal areas.

In winter, ice fog is the major restriction to aircraft operation. Blowing and drifting snow often restrict visibility also. Storms and well-defined frontal passages frequent the coastal areas accompanied by turbulence, especially in the coastal mountains.

Icing is most frequent in spring and fall and may extend to high levels in active, turbulent frontal zones. Fog is also a source of icing when temperature is colder than freezing.

CONTINENTAL AREAS

Over the continental interior, good flying weather prevails much of the year; although during winter, ice fog often restricts aircraft operations. In terms of ceiling and visibility, the summer months provide the best flying weather. However, the number of cloudy days during the summer exceeds those in winter. Thunderstorms develop on occasion during the summer, but they usually can be circumnavigated without much interference with flight plans.

IN CLOSING

If one were to summarize general weather conditions and flight precautions over Alaska, northern Canada, and the Arctic, he would say:

1. Interior areas generally have good flying weather, but coastal areas and Arctic slopes often are plagued by low ceiling, poor visibility, and icing.
2. "Whiteout" conditions over ice and snow covered areas often cause pilot disorientation.
3. Flying conditions are usually worse in mountain passes than at reporting stations along the route.
4. Routes through the mountains are subject to strong turbulence, especially in and near passes.
5. Beware of a false mountain pass that may lead to a dead-end.
6. Thundershowers sometimes occur in the interior during May through August. They are usually circumnavigable and generally move from northeast to southwest.
7. Always file a flight plan. Stay on regularly traversed routes, and if downed, stay with your plane.
8. If lost during summer, fly down-drainage, that is, downstream. Most airports are located near rivers, and chances are you can reach a landing strip by flying downstream. If forced down, you will be close to water on which a rescue plane can land. In summer, the tundra is usually too soggy for landing.
9. Weather stations are few and far between. Adverse weather between stations may go undetected unless reported by a pilot in flight. A report confirming good weather between stations is also just as important. ***Help yourself and your fellow pilot by reporting weather en route.***

Chapter 15 TROPICAL WEATHER

Technically, the Tropics lie between latitudes 23~2° N and 23~/2° S. However, weather typical of this region sometimes extends as much as 45° from the Equator. One may think of the Tropics as uniformly rainy, warm, and humid. The facts are, however, that the Tropics contain both the wettest and driest regions of the world. This chapter describes the circulation basic to the Tropics terrain influences that determine arid and wet regions. and transitory systems that invade or disturb the basic tropical circulation.

CIRCULATION

In chapter 4, we learned that wind blowing out of the subtropical high pressure belts toward the Equator form the northeast and southeast trade winds of the two hemispheres. These trade winds converge in the vicinity of the Equator where air rises. This convergence zone is the "intertropical convergence zone" (ITCZ). In some areas of the world, seasonal temperature differences between land and water areas generate rather large circulation patterns that overpower the trade wind circulation; these areas arc "monsoon" regions. Tropical weather discussed here includes the subtropical high pressure belts, the trade wind belts, the intertropical convergence zone, and monsoon regions.

SUBTROPICAL HIGH PRESSURE BELTS

If the surface under the subtropical high pressure belts were all water of uniform temperature, the high pressure belts would be continuous highs around the globe. The belts would be areas of descending or subsiding air and would be characterized by strong temperature inversions and very little precipitation. However, land surfaces at the latitudes of the high pressure belts are generally warmer throughout the year than are water surfaces. Thus, the high pressure belts are broken into semipermanent high pressure anticyclones over oceans with troughs or lows over continents as shown in figures 23 and 24, chapter 4. The subtropical highs shift southward during the Northern Hemisphere winter and northward during summer. The seasonal shift, the height and strength of the inversion, and terrain features determine weather in the subtropical high pressure belts.

Continental Weather

Along the west coasts of continents under a subtropical high, the air is stable. The inversion is strongest and lowest where the east side of an anticyclone overlies the west side of a continent. Moisture is trapped under the inversion; fog and low stratus occur frequently. However, precipitation is rare since the moist layer is shallow and the air is stable. Heavily populated areas also add contaminants to the air which, when trapped under the inversion, create an air pollution problem.

The extreme southwest m United States, for example, is dominated in summer by a subtropical high. We are all familiar with the semi-arid summer climate of southern California. Rainfall is infrequent but fog is common along the coast. Contaminants trapped along with fog under the strong inversion may persist for days creating "smog."

In winter, the subtropical high pressure belts shift southward. Again, let's consider southern California as an example. In winter, the area comes under the influence of midlatitude circulation which increases frequency of rain. Also, an occasional wintertime outbreak of polar air brings clear skies with excellent visibility.

The situation on eastern continental coasts is just the opposite. The inversion is weakest and highest where the west side of an anticyclone overlies the eastern coast of a continent. Convection can penetrate the inversion, and showers and thunderstorms often develop. Precipitation is generally sufficient to support considerable vegetation. For example, in the United States, Atlantic coastal areas at the same latitude as southern California are far from arid in summer.

Low ceiling and fog often prevent landing at a west coast destination, but a suitable alternate generally is available a few miles inland. Alternate selection may be more critical for an eastern coast destination because of widespread instability and associated hazards.

Weather over Open Sea

Under a subtropical high over the open sea, cloudiness is scant. The few clouds that do develop have tops from 3,000 to 6,000 feet depending on height of the inversion. Ceiling and visibility are generally quite ample for VFR flight.

Island Weather

An island under a subtropical high receives very little rainfall because of the persistent temperature inversion. Surface heating over some larger islands causes light convective showers. Cloud tops are only slightly higher than over open water. Temperatures are mild, showing small seasonal and diurnal changes. A good example is the pleasant, balmy climate of Bermuda.

TRADE WIND BELTS

Figures 138 and 139 show prevailing winds throughout the Tropics for July and January. Note that trade winds blowing out of the subtropical highs over ocean areas are predominantly northeasterly in the Northern Hemisphere and southeasterly in the Southern Hemisphere. The inversion from the subtropical highs is carried into the trade winds and is known as the "trade wind inversion." As in a subtropical high, the inversion is strongest where the trades blow away from the west coast of a continent and weakest where they blow onto an eastern continental shore. Daily variations from these prevailing directions are small except during tropical storms. As a result, weather at any specific location in a trade wind belt varies little from day to day.

Weather over Open Sea

In the trade wind belt, skies over open water are about one-half covered by clouds on the average. Tops range from 3,000 to 8,000 feet depending on height of the inversion. Showers, although more common than under a subtropical high, are still light with comparatively little rainfall. Flying weather generally is quite good.

Continental Weather

Where trade winds blow offshore along the west coasts of continents, skies are generally clear and the area is quite arid. The Baja Peninsula of lower California is a well-known example. Where trade winds blow onshore on the east sides of continents, rainfall is generally abundant in showers and occasional thunderstorms. The east coast of Mexico is a good example. Rainfall may be carried a considerable distance inland where the worlds are not blocked by a mountain barrier. Inland areas blocked by a mountain barrier are deserts; examples are the Sahara Desert and the arid regions of southwestern United States. Afternoon convective currents are common over arid regions due to strong surface heating. Cumulus and cumulonimbus clouds can develop, but cloud bases are high and rainfall is scant because of the low moisture content.

Flying weather along eastern coasts and mountains is subject to the usual hazards of showers and thunderstorms. Flying over arid regions is good most of the time but can be turbulent in afternoon convective currents; be especially aware of dust devils. Blowing sand or dust sometimes restricts visibility.

Island Weather

Mountainous islands have the most dramatic effect on trade wind weather. Since trade winds are consistently from approximately the same direction, they always strike the same side of the

island; this side is the windward side. The opposite side is the leeward side. Winds blowing up the windward side produce copious and frequent rainfall, although cloud tops rarely exceed 10,000 feet. Thunderstorms are rare. Downslope winds on the leeward slopes dry the air leaving relatively clear skies and much less rainfall. Many islands in the trade wind belt have lush vegetation and even rain forests on the windward side while the leeward is semiarid. For example, the island of Oahu, Hawaii, is about 24 miles wide in the direction of the trade winds. Annual rainfall averages from about 60 inches on the windward coast to 200 inches at the mountain tops, decreasing to 10 inches on the leeward shore.

The greatest flying hazard near these islands is obscured mountain tops. Ceiling and visibility occasionally restrict VFR flight on the windward side in showers. IFR weather is virtually nonexistent on leeward slopes.

Islands without mountains have little effect on cloudiness and rainfall. Afternoon surface heating increases convective cloudiness slightly, but shower activity is light. However, any island in either the subtropical high pressure belt or trade wind belt enhances cumulus development even though tops do not reach great heights. Therefore, a cumulus top higher than the average tops of surrounding cumulus usually marks the approximate location of an island. If it becomes necessary to "ditch" in the ocean, look for a tall cumulus. If you see one, head for it. It probably marks a land surface, increasing your chances of survival.

THE INTERTROPICAL CONVERGENCE ZONE (ITCZ)

Converging winds in the intertropical convergence zone (ITCZ) force air upward. The inversion typical of the subtropical high and trade wind belts disappears. Figures 138 and 139 show the ITCZ and its seasonal shift. The ITCZ is well marked over tropical oceans but is weak and illdefined over large continental areas.

Weather over Islands and Open Water

Convection in the ITCZ carries hug quantities of moisture to great heights. Showers and thunderstorms frequent the ITCZ and tops to 40,000 feet or higher are common as shown in figure 137. Precipitation is copious. Since convection dominates the ITCZ, there is little difference in weather over islands and open sea under the ITCZ.

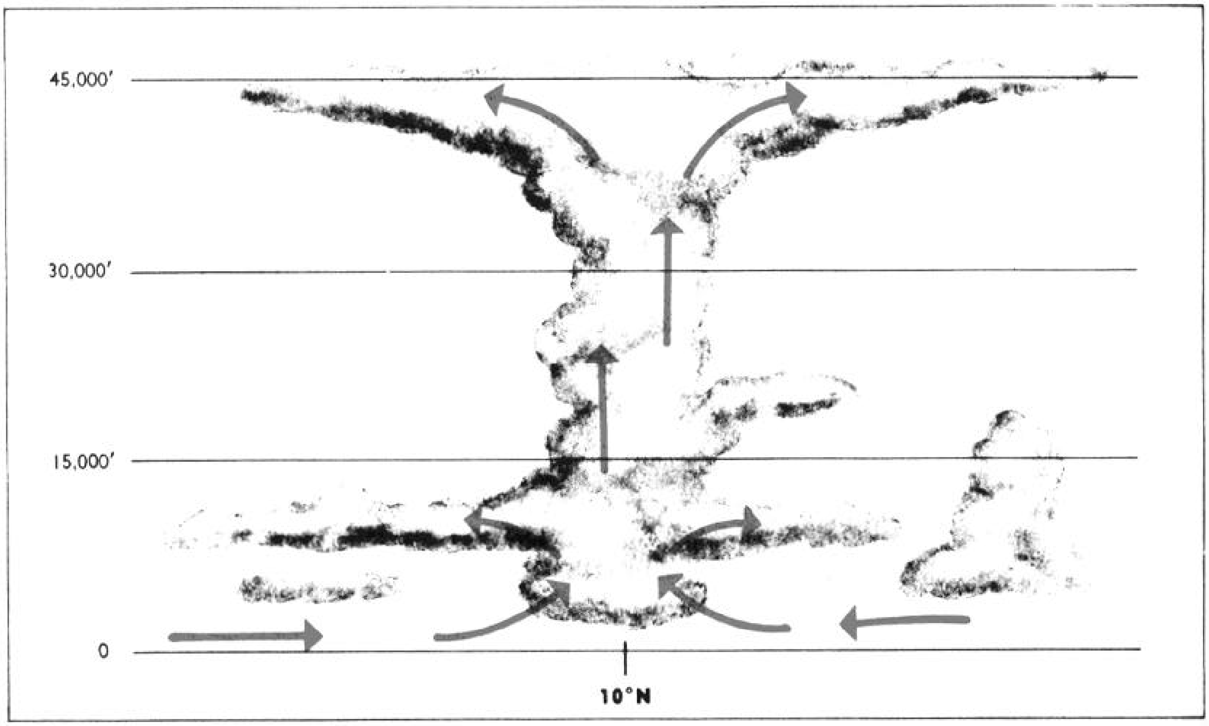


FIGURE 137. Vertical cross section illustrating convection in the Intertropical Convergence Zone.

Flying through the ITCZ usually presents no great problem if one follows the usual practice of avoiding thunderstorms. He usually can find a safe corridor between storms.

Since the ITCZ is ill-defined over continents, we will not attempt to describe ITCZ continental weather as such. Continental weather ranges from arid to rain forests and is more closely related to the monsoon than to the ITCZ.

MONSOON

If you refer again to figures 23 and 24 in chapter 4, you can see that over the large land mass of Asia, the subtropical high pressure breaks down completely. Asia is covered by an intense high during the winter and a well-developed low during the summer. You can also see the same over Australia and central Africa, although the seasons are reversed in the Southern Hemisphere.

The cold, high pressures in winter cause wind to blow from the deep interior outward and offshore. In summer, wind direction reverses and warm moist air is carried far inland into the low pressure area. This large scale seasonal wind shift is the "monsoon." The most notable monsoon is that of southern and southeastern Asia.

Summer or Wet Monsoon Weather

During the summer, the low over central Asia draws warm, moist, unstable maritime air from the southwest over the continent. Strong surface heating coupled with rising of air flowing up the higher terrain produces extensive cloudiness, copious rain, and numerous thunderstorms. Rainfall at some stations in India exceeds 400 inches per year with highest amounts between June and October.

The monsoon is so pronounced that it influences circulation many miles out over the ocean. Note in figure 138 that in summer, prevailing winds from the Equator to the south Asian coast are southerly and southeasterly; without the monsoon influence, these areas would be dominated by northeasterly trades. Islands within the monsoon influence receive frequent showers.

Winter Monsoon Weather

Note in figure 139 how the winter flow has reversed from that shown in figure 138. Cold, dry air from the high plateau deep in the interior warms adiabatically as it flows down the southern slopes of the Himalayan Mountains. Virtually no rain falls in the interior in the dry winter monsoon. As the

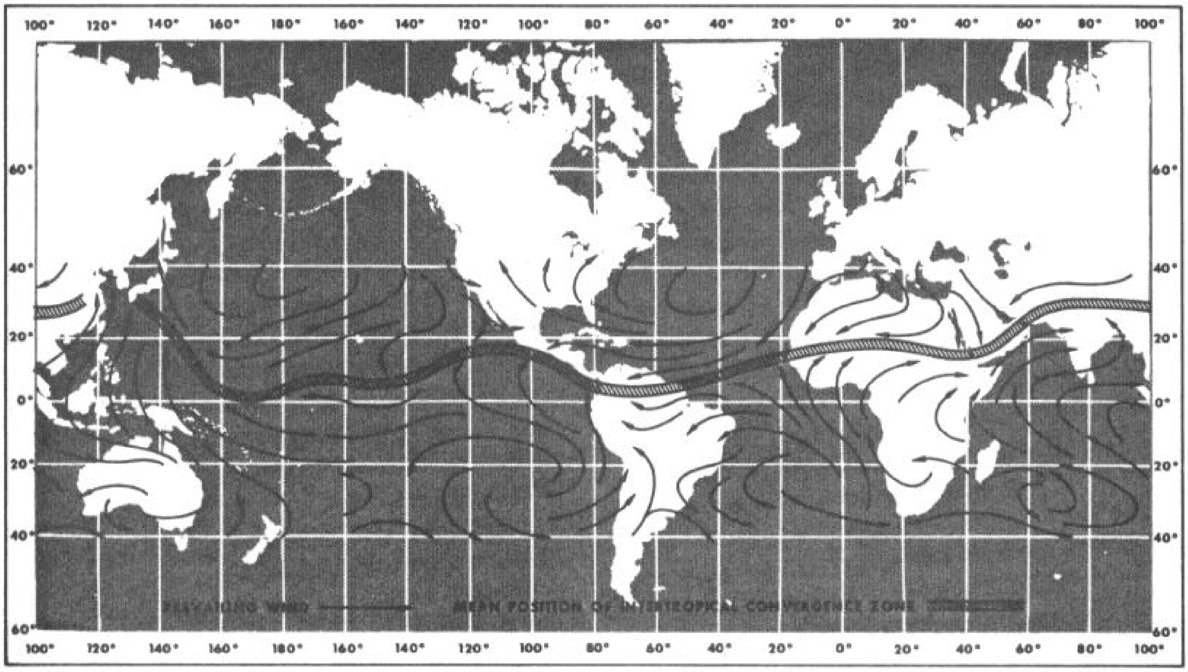


FIGURE 138. Prevailing winds throughout the Tropics in July. Remember that in the Southern Hemisphere, circulation around pressure centers is opposite that in the Northern Hemisphere.

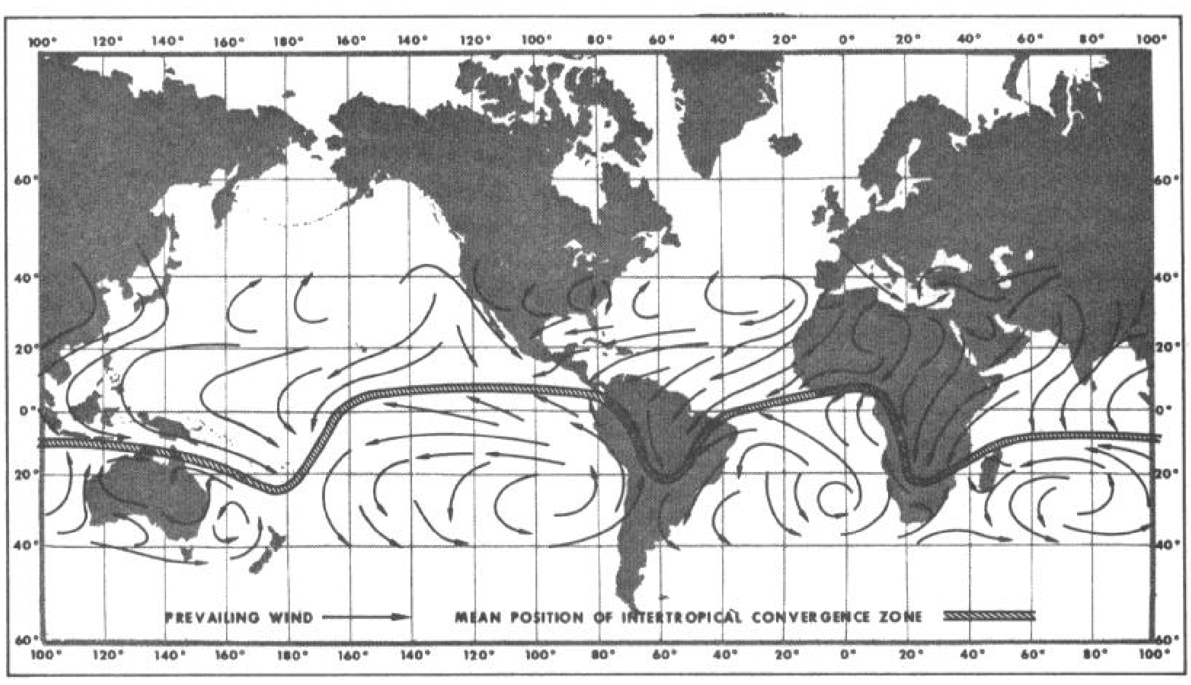


FIGURE 139. Prevailing winds in the Tropics in January.

dry air moves off shore over warmer water, it rapidly takes in more moisture, becomes warmer in low levels and, therefore, unstable. Rain is frequent over off-shore is}ands and even along coastal areas after the air has had a significant over-water trajectory.

The Philippine Islands are in an area of special interest. During the summer, they are definitely in southerly monsoon flow and are subjected to abundant rainfall. In the winter, wind over the Philippines is northeasterly—in the transition zone between the northeasterly trades and the monsoon flow. It is academic whether we call the phenomenon the trade winds or monsoon; in either case, it produces abundant rainfall. The Philippines have a year-round humid, tropical climate.

Other Monsoon Areas

Australia in July (Southern Hemisphere winter) is an area of high pressure with predominantly offshore winds as shown in figure 138. Most of the continent is dry during the winter. In January, figure 139, winds are onshore into the continental low pressure. However, most of Australia is rimmed by mountains, coastal regions are wet where the onshore winds blow up the mountain slopes. The interior is arid where down-slope winds are warmed and dried.

Central Africa is known for its humid climate and jungles. Note in figures 138 and 139 that prevailing wind is onshore much of the year over these regions. Some regions are wet the year round; others have the seasonal monsoon shift and have a summer wet season and a winter dry season. Climate of Africa is so varied that only a detailed area-by-area study can explain the climate typical of each area.

In the Amazon Valley of South America during the Southern Hemisphere winter (July), southeast trades, as shown in figure 138, penetrate deep into the valley bringing abundant rainfall which contributes to the jungle climate. In January, the ITCZ moves south of the valley as shown in figure 139. The northeast trades are caught up in the monsoon, cross the Equator, and also penetrate the Amazon Valley. The jungles of the Amazon result largely from monsoon winds.

Flying Weather in Monsoons

During the winter monsoon, excellent flying weather prevails over dry interior regions. Over water, one must pick his way around showers and thunderstorms. In the summer monsoon, VFR flight over land is often restricted by low ceilings and heavy rain. IFR flight must cope with the hazards of thunderstorms. Freezing level in the Tropics is quite high—14,000 feet or higher—so icing is restricted to high levels.

TRANSITORY SYSTEMS

So far, we have concentrated on prevailing circulations. Now, let's turn to migrating tropical weather producers—the shear line, trough aloft, tropical wave, and tropical cyclone.

SHEAR LINE

A wind shear line found in the Tropics mainly results from midlatitude influences. In chapter 8 we stated that an air mass becomes modified when it flows from its source region. By the time a cold air mass originating in high latitudes reaches the Tropics, temperature and moisture are virtually the same on both sides of the front. A shear line, or wind shift, is all that remains. A shear line also results when a semi-permanent high splits into two cells inducing a trough as shown in figure 140.

These shear lines are zones of convergence creating forced upward motion. Consequently, considerable thunderstorm and rain shower activity occurs along a shear line.

TROUGH ALOFT

Troughs in the atmosphere, generally at or above 10,000 feet, move through the Tropics, especially along the poleward fringes. Figure 141 shows such a trough across the Hawaiian Island chain. As a trough moves to the southeast or east, it spreads middle and high cloudiness over extensive areas to the east of the trough line. Occasionally, a welldeveloped trough will extend deep into the Tropics, and a closed low forms at the equatorial end of the trough. The low then may separate from the trough and move westward producing a large amount of cloudiness and precipitation. If this occurs in the vicinity of a strong subtropical jet stream, extensive

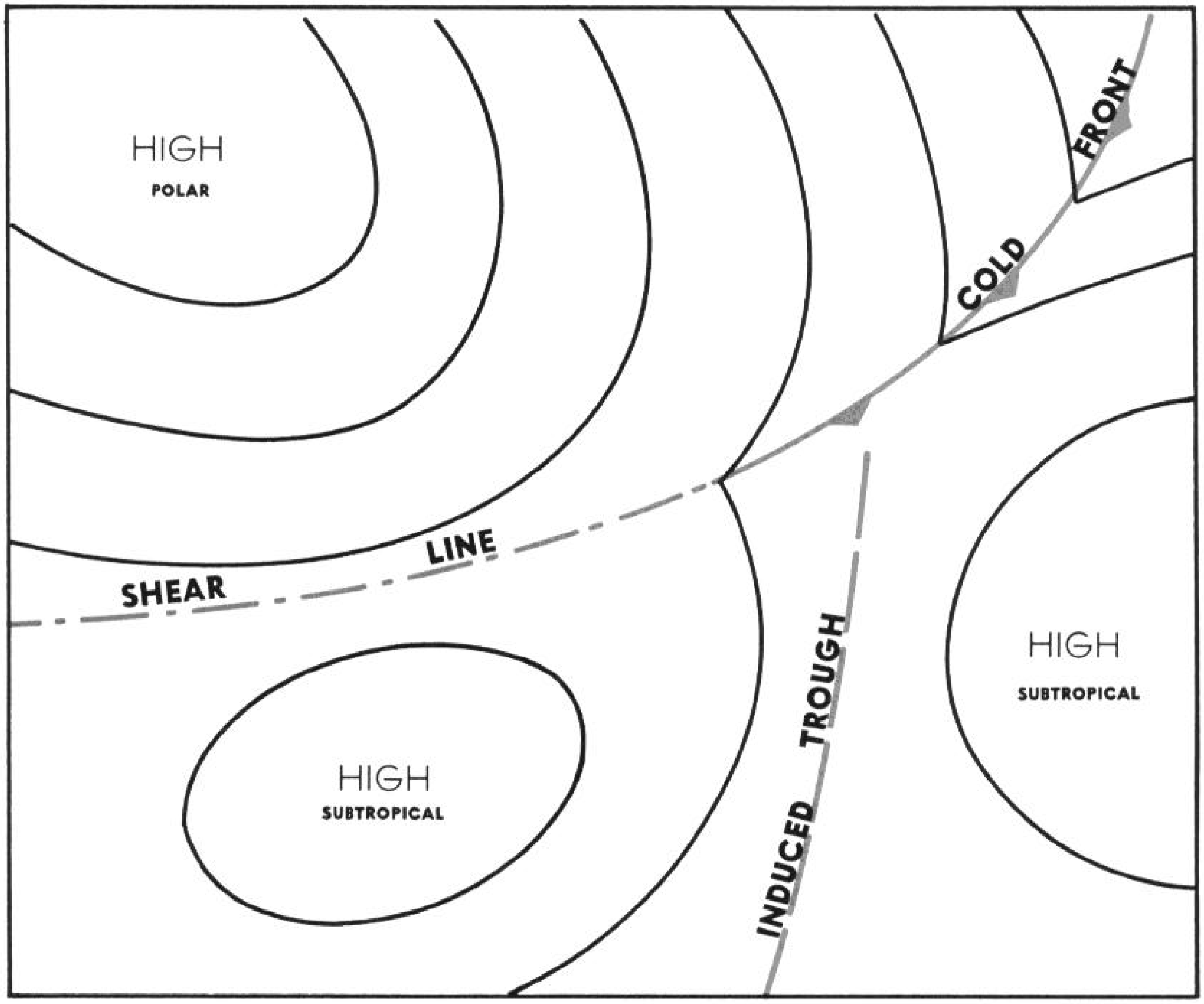


FIGURE 140. A shear line and an induced trough caused by a polar high pushing into the subtropics.

and sometimes dense cirrus and some convective and clear air turbulence often develop.

Troughs and lows aloft produce considerable amounts of rainfall in the Tropics, especially over land areas where mountains and surface heating lift air to saturation. Low pressure systems aloft contribute significantly to the record 460 inches average annual rainfall on Mt. Waialeale on Kauai, Hawaii. Other mountainous areas of the Tropics are also among the wettest spots on earth.

TROPICAL WAVE

Tropical waves (also called easterly waves) are common tropical weather disturbances, normally occurring in the trade wind belt. In the Northern Hemisphere, they usually develop in the southeastern perimeter of the subtropical high pressure systems. They travel from east to west around the southern fringes of these highs in the prevailing easterly circulation of the Tropics. Surface winds in advance of a wave are somewhat more northerly than the usual trade wind direction. As the wave approaches, as shown in figure 142, pressure falls; as it passes, surface wind shifts to the east-southeast or southeast. The typical wave is preceded by very good weather but followed by extensive cloudiness, as shown in figure 143, and often by rain and thunderstorms. The weather activity is roughly in a north-south line.

Tropical waves occur in all seasons, but are more frequent and stronger during summer and early fall. Pacific waves frequently affect Hawaii; Atlan-

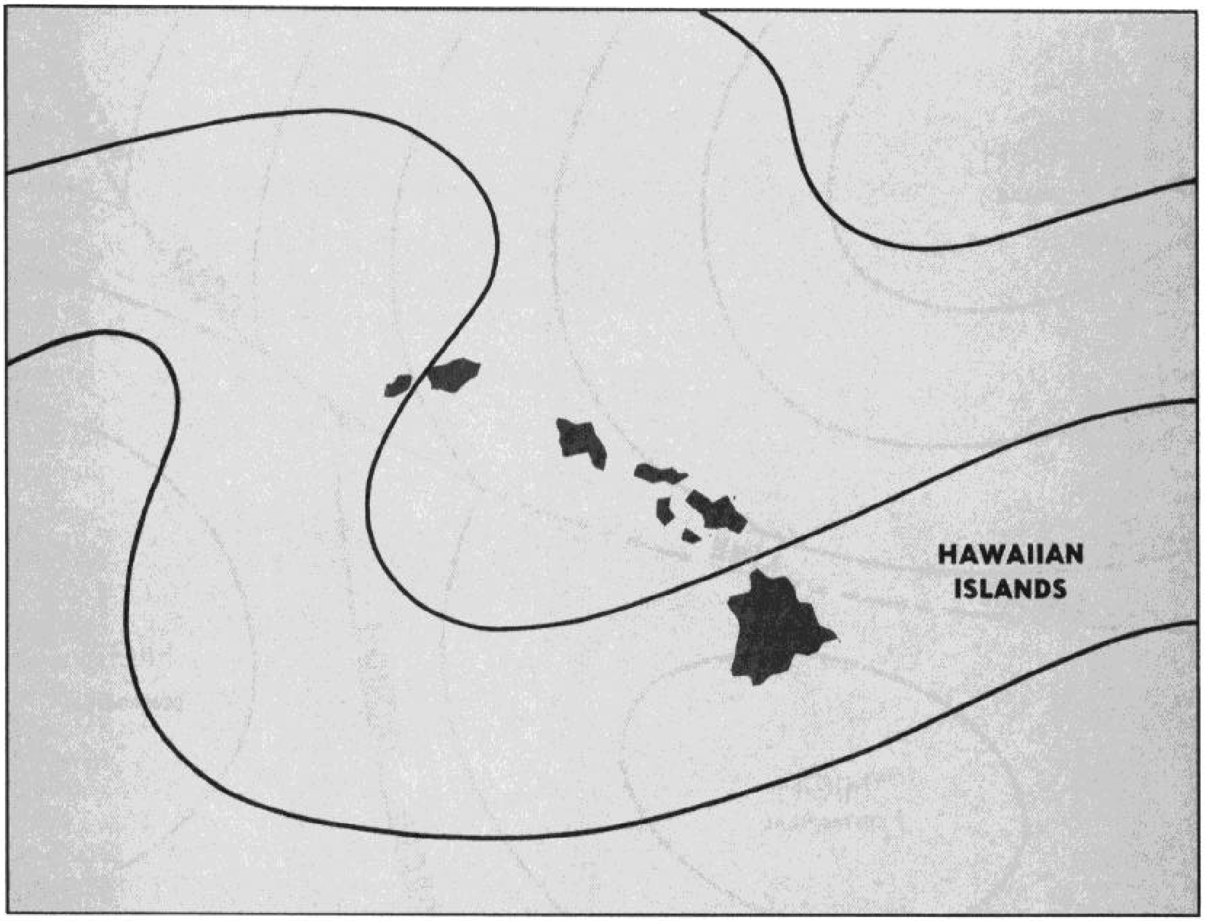


FIGURE 141. A trough aloft across the Hawaiian Islands. Extensive cloudiness develops east of the trough.

tic waves occasionally move into the Gulf of Mexico, reaching the U.S. coast.

TROPICAL CYCLONE

Tropical cyclone is a general term for any low that originates over tropical oceans. Tropical cyclones are classified according to their intensity based on average one-minute wind speeds. Wind gusts in these storms may be as much as 50 percent higher than the average one-minute wind speeds. Tropical cyclone international classifications are:

(1) Tropical Depression—highest sustained winds up to 34 knots (64 km/h),

(2) Tropical Storm—highest sustained winds of 35 through 64 knots (65 to 119 km/ h), and

(3) Hurricane or Typhoon—highest sustained winds 65 knots (120 km/h) or more.

Strong tropical cyclones are known by different names in different regions of the world. A tropical cyclone in the Atlantic and eastern Pacific is a "hurricane"; in the western Pacific, "typhoon"; near Australia, "willy-willy"; and in the Indian Ocean, simply "cyclone." Regardless of the name, these tropical cyclones produce serious aviation hazards. Before we delve into these aspects, let's look at the development, movement, and decay of these cyclones.

Development

Prerequisite to tropical cyclone development are optimum sea surface temperature under weather systems that produce low-level convergence and cyclonic wind shear. Favored breeding grounds are tropical (easterly) waves, troughs aloft, and areas of converging northeast and southeast trade winds along the intertropical convergence zone.

The low level convergence associated with these systems, by itself, will not support development of a tropical cyclone. The system must also have

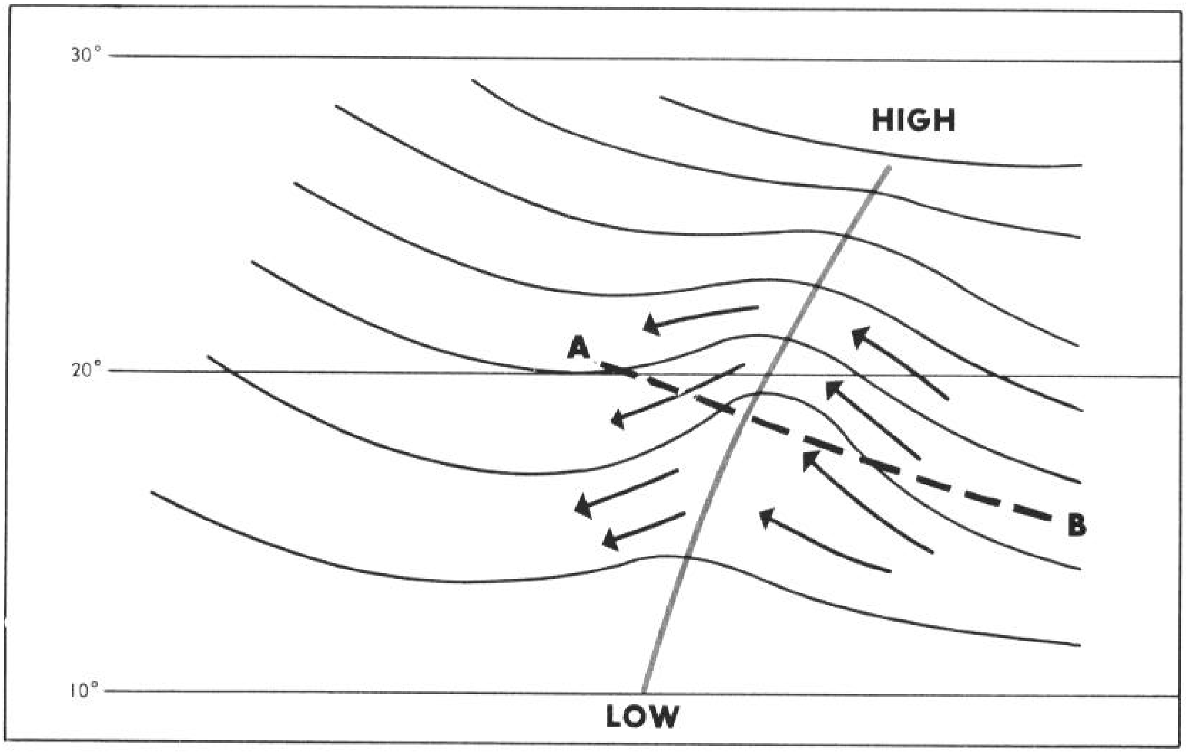


FIGURE 142. A Northern Hemisphere easterly wave. Progressing from (B) to (A), note that winds shift generally from southeasterly to northeasterly. The wave moves toward the west and is often preceded by good weather and followed by extensive cloudiness and precipitation.

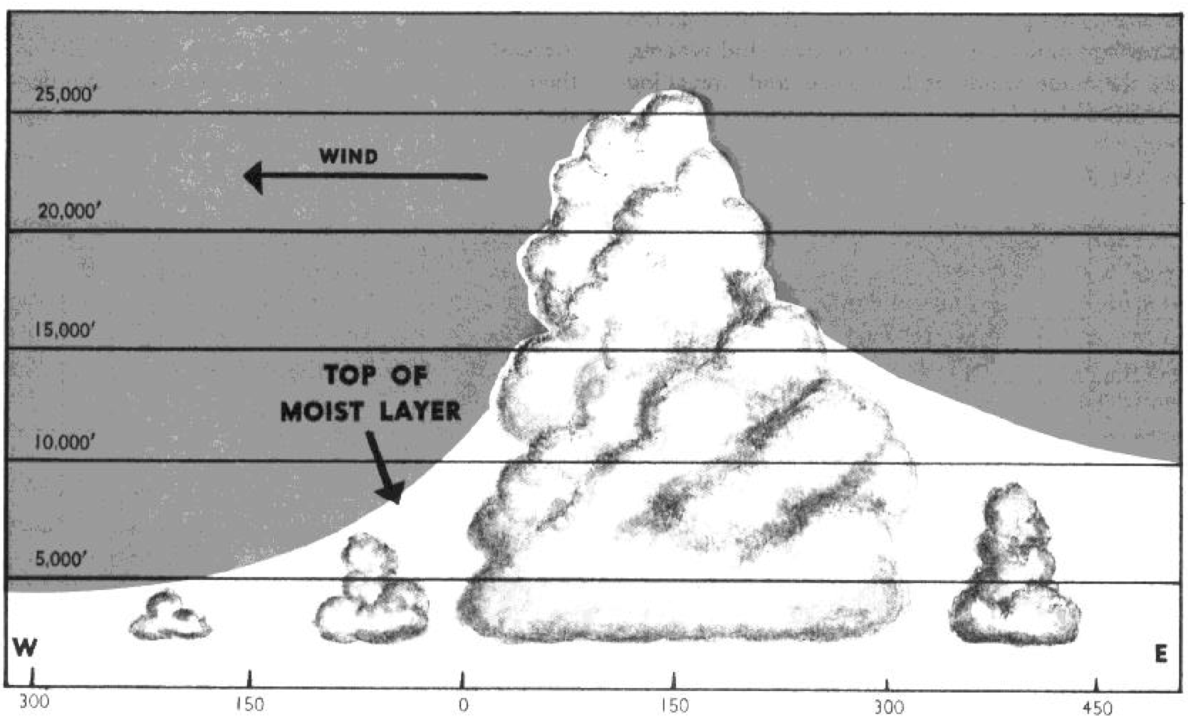


FIGURE 143. Vertical cross section along line A—B in figure 142.

horizontal outflow—divergence—at high tropospheric levels. This combination creates a "chimney," in which air is forced upward causing clouds and precipitation. Condensation releases large quantities of latent heat which raises the temperature of the system and accelerates the upward motion. The rise in temperature lowers the surface pressure which increases low-level convergence. This draws more moisture-laden air into the system. When these chain-reaction events continue, a huge vortex is generated which may culminate in hurricane force winds.

Figure 144 shows regions of the world where tropical cyclones frequently develop. Notice that they usually originate between latitudes 5° and 20°. Tropical cyclones are unlikely within 5° of the Equator because the Coriolis force is so small near the Equator that it will not turn the winds enough for them to flow around a low pressure area. Winds flow directly into an equatorial low and rapidly fill it.

Movement

Tropical cyclones in the Northern Hemisphere usually move in a direction between west and northwest while in low latitudes. As these storms move toward the midlatitudes, they come under the influence of the prevailing westerlies. At this time the storms are under the influence of t--o wind systems, i.e., the trade winds at low levels and prevailing westerlies aloft. Thus a storm may move very errat-
ically and may even reverse course, or circle. Finally, the prevailing westerlies gain control and the storm recurves toward the north, then to the northeast, and finally to the east-northeast. By this time the storm is well into midlatitudes.

Decay

As the storm curves toward the north or east, it usually begins to lose its tropical characteristics and acquires characteristics of lows in middle latitudes. Cooler air flowing into the storm gradually weakens it. If the storm tracks along a coast line or over the open sea, it gives up slowly, carrying its fury to areas far removed from the Tropics. However, if the storm moves well inland, it loses its moisture source and weakens from starvation and increased surface friction, usually after leaving a trail of destruction and flooding.

When a storm takes on middle latitude characteristics, it is said to be "extratropical" meaning "outside the Tropics." Tropical cyclones produce weather conditions that differ somewhat from those produced by their higher latitude cousins and invite our investigation.

Weather in a Tropical Depression

While in its initial developing stage, the cyclone is characterized by a circular area of broken to overcast clouds in multiple layers. Embedded in these clouds are numerous showers and thunderstorms Rain shower and thunderstorm coverage

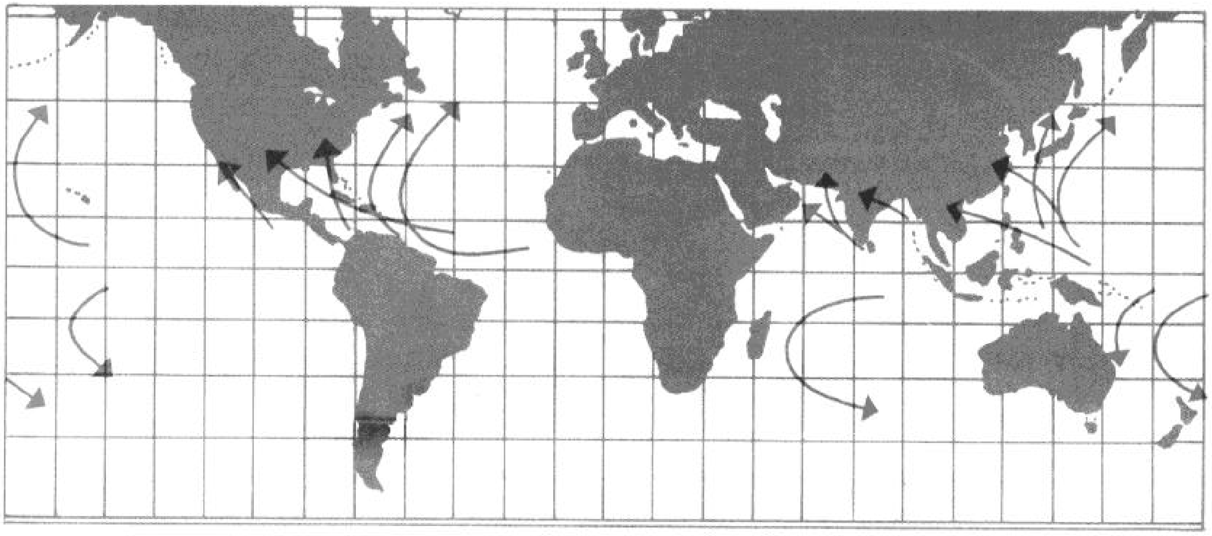


FIGURE 144. Principal regions where tropical cyclones form and their favored directions of movement.

varies from scattered to almost solid Diameter of the cloud pattern varies from less than 100 miles in small systems to well over 200 miles in large ones.

Weather in Tropical Storms and Hurricanes

As cyclonic flow increases, the thunderstorms and rain showers form into broken or solid lines paralleling the wind flow that is spiraling into the center of the storm These lines are the spiral rain bands frequently seen on radar. These rain bands continually change as they rotate around the storm. Rainfall in the rain bands is very heavy, reducing ceiling and visibility to near zero. Winds are usually very strong and gusty and, consequently, generate violent turbulence Between the rain bands, ceilings and visibilities are somewhat better, and turbulence generally is less intense.

The "eye" usually forms in the tropical storm stage and continues through the hurricane stage. In the eye, skies are free of turbulent cloudiness, and wind is comparatively light. The average diameter of the eye is between 15 and 20 miles, but sometimes is as small as 7 miles and rarely is more than 30 miles in diameter. Surrounding the eye is a wall of cloud that may extend above 50,000 feet. This "wall cloud" contains deluging rain and the strongest winds of the storm. Maximum wind speeds of 175 knots have been recorded in some storms. Figure 145 is a radar display and 146, a satellite photograph of a mature hurricane. Note the spiral rain bands and the circular eye. Notice the similarity between these two figures.

Detection and Warning

The National Weather Service has a specialized hurricane forecast and warning service center at Miami, Florida, which maintains constant watch for the formation and development of tropical cyclones. Weather information from land stations, ships at sea, reconnaissance aircraft, long range radars, and weather satellites is fed into the center. The center forecasts the development, movement, and intensity of tropical cyclones. Forecasts and warnings are issued to the public and aviation interests by field offices of the National Weather service.

Flying

All pilots except those especially trained to explore tropical storms and hurricanes should AVOID THESE DANGEROUS STORMS. Occasionally, jet aircraft have been able to fly over small and less intense storms, but the experience of weather research aircraft shows hazards at all levels within them.

Tops of thunderstorms associated with tropical cyclones frequently exceed 50,000 feet. Winds in a typical hurricane are strongest at low levels, decreasing with altitude. However, research aircraft have frequently encountered winds in excess of 100 knots at 18,000 feet. Aircraft at low levels are exposed to sustained, pounding turbulence due to the surface friction of the fast-moving air. Turbulence increases in intensity in spiral rain bands and becomes most violent in the wall cloud surrounding the eye.

An additional hazard encountered in hurricanes is erroneous altitude readings from pressure altimeters. These errors are caused by the large pressure difference between the periphery of the storm and its center. One research aircraft lost almost 2,000 feet true altitude traversing a storm while the pressure altimeter indicated a constant altitude of 5,000 feet.

In short, tropical cyclones are very hazardous, so avoid them ! To bypass the storm in a minimum of time, fly to the right of the storm to take advantage of the tailwind. If you fly to the left of the storm, you will encounter strong headwinds which may exhaust your fuel supply before you reach a safe landing area.

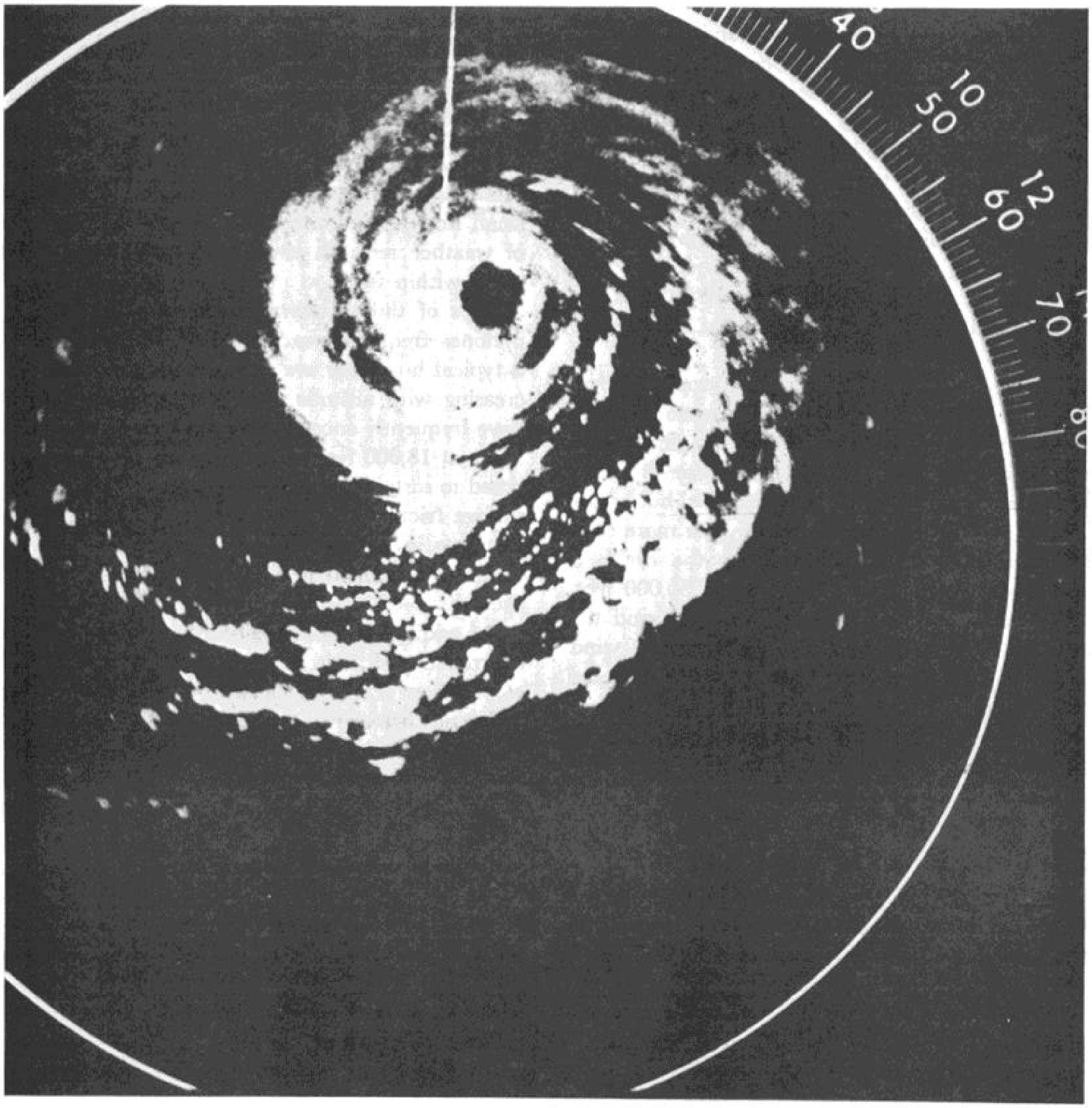


FIGURE 145. Radar photograph of hurricane "Donna" observed at Key West, Florida.

FIGURE 146. A hurricane observed by satellite.

Chapter 16 SOARING WEATHER

While horse racing may be the "Sport of Kings," soaring may be considered the "King of Sports." Soaring bears the relationship to flying that sailing bears to power boating. Soaring has made notable contributions to meteorology. For example, soaring pilots have probed thunderstorms and mountain waves with findings that have made flying safer for all pilots. However, soaring is primarily recreational.

A sailplane must have auxiliary power to become airborne such as a winch, a ground tow, or a tow by a powered aircraft. Once the sailcraft is airborne and the tow cable released, performance of the craft depends on the weather and the skill of the pilot. Forward thrust comes from gliding downward relative to the air the same as thrust is developed in a power-off glide by a conventional aircraft. Therefore, to gain or maintain altitude, the soaring pilot must rely on upward motion of the air. To a sailplane pilot, "lift" means the rate of climb he can achieve in an up-current, while "sink" denotes his rate of descent in a downdraft or in neutral air. "Zero sink" means that upward currents are just strong enough to enable him to hold altitude but not to climb. Sailplanes are highly efficient machines; a sink rate of a mere 2 feet per second provides an airspeed of about 40 knots, and a sink rate of 6 feet per second gives an airspeed of about 70 knots. Some two-place training craft have somewhat higher sink rates.

In lift, a sailplane pilot usually flies 35 to 40 knots with a sink rate of about 2 feet per second. Therefore, if he is to remain airborne, he must have an upward air current of at least 2 feet per second. There is no point in trying to soar until weather conditions favor vertical speeds greater than the minimum sink rate of the aircraft. These vertical currents develop from several sources, and these sources categorize soaring into five classes: (1) Thermal Soaring, (2) Frontal Soaring, (3) Sea Breeze Soaring, (4) Ridge or Hill Soaring, and (5) Mountain Wave Soaring.

THERMAL SOARING

Peter Dixon estimates that about 80 percent of all soaring in the U.S. depends on thermal lift.* What is a thermal? A thermal is simply the updraft in a small-scale convective current. Chapter 4 in the section "Convection," and chapter 9 in the section, "Convective Currents," explain the basic principle of convective circulation. The explanations are adequate for the pilot of a powered aircraft; but to the soaring pilot, they are only a beginning.

All pilots scan the weather pattern for convective activity. Remember that turbulence is proportional to the speed at which the aircraft penetrates adjacent updrafts and downdrafts. The fast moving powered aircraft experiences "pounding" and tries to avoid convective turbulence. The slower moving soaring pilot enjoys a gradual change from thermals to areas of sink. He chases after local convective cells using the thermals for lift.

A soaring aircraft is always sinking relative to the air. To maintain or gain altitude, therefore, the soaring pilot must spend sufficient time in thermals to overcome the normal sink of the aircraft as well as to regain altitude lost in downdrafts. He usually circles at a slow airspeed in a thermal and then darts on a beeline to the next thermal as shown in figure 147.

Low-level heating is prerequisite to thermals; and this heating is mostly from the sun, although

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*Peter L. Dixon. SOARING, page 129; 1970; Ballantine Books, New York City.

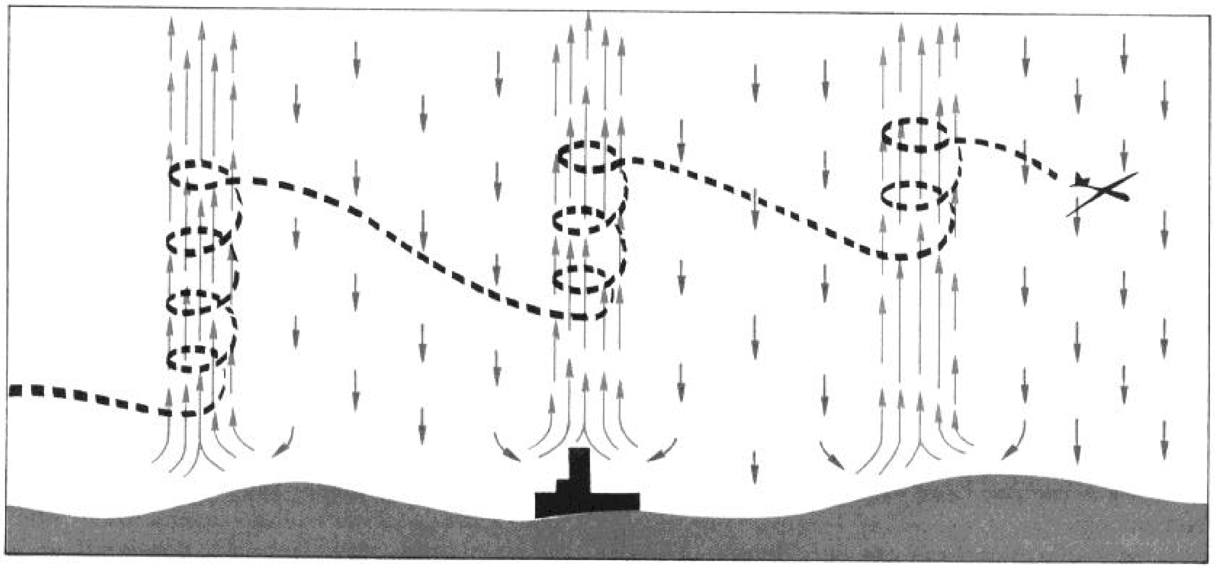

FIGURE 147. Thermals generally occur over a small portion of an area while downdrafts predominate. Updrafts in the thermals usually are considerably stronger than the downdrafts. Sailplane pilots gain altitude in thermals and hold altitude loss in downdrafts to a minimum.

it may be augmented by man-made heat sources such as chimneys, factories, and cities. Cool air must sink to force the warm air upward in thermals. Therefore, in small-scale convection, thermals and downdrafts coexist side by side. The net upward displacement of air must equal the net downward displacement. Fast rising thermals generally cover a small percentage of a convective area while slower downdrafts predominate over the remaining greater portion as diagrammed in figure 147.

Since thermals depend on solar heating, thermal soaring is restricted virtually to daylight hours with considerable sunshine. Air tends to become stable at night due to low-level cooling by terrestrial radiation, often resulting in an inversion at or near the surface (see Cs. 3 and 6). Stable air suppresses convection, and thermals do not form until the inversion "burns off" or lifts sufficiently to allow soaring beneath the inversion. The earliest that soaring may begin varies from early forenoon to early afternoon, the time depending on the strength of the inversion and the amount of solar heating. Paramount to a pilot's soaring achievement is his skill in diagnosing and locating thermals.

LOCATING THERMALS

Since convective thermals develop from uneven heating at the surface, the most likely place for a thermal is above a surface that heats readily.

Types of Terrain Surfaces

When the sky is cloudless, the soaring pilot must look for those surfaces that heat most rapidly and seek thermals above those areas. Barren sandy or rocky surfaces, plowed fields, stubble fields surrounded by green vegetation, cities, factories, chimneys, etc., are good thermal sources. A pilot learns through experience the most favorable spots in his local area. But terrain features are only part of the story; time of day influences not only *when* thermals form but also *where*.

Sun Angle

Angle of the sun profoundly affects location of thermals over hilly landscapes. During early forenoon, the sun strikes eastern slopes more directly than other slopes; therefore, the most favorable areas for thermals are eastern slopes. The favorable areas move to southern slopes during midday. In the afternoon, they move to western slopes before they begin to weaken as the evening sun sinks

toward the western horizon. For example, if a rocky knob protrudes above a grassy plain, the most likely area of thermals is over the eastern slope in the forenoon and the western slope in the afternoon. Once a pilot has sighted a likely surface, he may look for other visual cues.

Dust and Smoke

Surface winds must converge to feed a rising thermal; so when you sight a likely spot for a thermal, look for dust or smoke movement near the surface. If you can see dust or smoke "streamers" from two or more sources converging on the spot as shown in figure 148(A), you have chosen wisely. If, however, the streamers diverge as shown in figure 148(B), a downdraft most likely hovers over the spot and it's time to move on.

Rising columns of smoke from chimneys and factories mark thermals augmented by man-made sources. These rising columns are positive indication of thermals. They are good sources of lift if upward speed is great enough to support the aircraft and if they are broad enough to permit circling. Towns or cities may provide thermals; but to use a thermal over a populated area, the pilot must have sufficient altitude to glide clear of the area in event the thermal subsides.

Dust Devils

Dust devils occur under sunny skies over sandy or dusty, dry surfaces and are sure signs of strong thermals with lots of lift. To tackle this excellent source of lift, you must use caution. The thermals are strong and turbulent and are surrounded by areas of little lift or possibly of sink.

If approaching the dust devil at too low an altitude, an aircraft may sink to an altitude too low for recovery. A recommended procedure is to always approach the whirling vortex at an altitude 500 feet or more above the ground. At this altitude, you have enough airspace for maneuvering in the event you get into a downdraft or turbulence too great for comfort.

A dust devil may rotate either clockwise or counterclockwise. Before approaching the dusty column, determine its direction of rotation by observing dust and debris near the surface. Philip

Wills* quotes R. H. Swinn, Chief Instructor of the Egyptian Gliding School, on approaching and en-

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*Philip Wills ON BEING A BIRD, page 79; 1953; Max Parrish and Co., Ltd.

tering a dust devil: "...at around 500 feet; the pilot turns towards the dust devil and cuts his speed as he approaches it to the minimum consistent with the control of the glider. As he nears the whirling column of sand he makes a circle on the outside of the dust devil against the direction of rotation, care being taken to give it a wider berth on the downwind side. In light of the variometer reading on the initial circle, closer contact is made with the column or a hasty retreat is beat to a safer orbit."

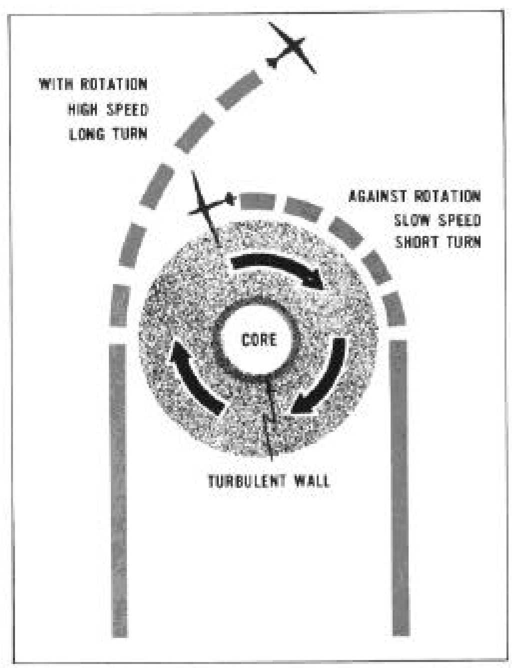

FIGURE 149. Horizontal cross section of a dust devil rotating clockwise. If the aircraft approaches the dust devil with the direction of rotation as on the left, increasing tailwind reduces airspeed and may result in loss of altitude or even a stall. When the pilot regains equilibrium, his circling speed is the sum of his airspeed and the tangential speed of the vortex; his radius of turn may be too great to remain in the thermal. When approaching against the rotation, the aircraft gains airspeed; circling speed is slowed as the tangential speed of the vortex is subtracted from airspeed. The pilot has much more freedom and latitude for maneuvering. At the center is a core providing little or no lift. Immediately surrounding the core is a turbulent wall.

Why should you enter against the direction of rotation? Figure 149 diagrams a horizontal cross section of a clockwise rotating dust devil and ways of entering it. If you enter with the direction of rotation as on the left, the wind speed is added to your airspeed giving you a fast circling speed probably too great to remain in the thermal. Against the rotation as on the right, wind speed is subtracted from airspeed giving you a slow circling speed.

Why slow your airspeed to a minimum? As you approach the increasing headwinds, the inertia of the aircraft causes a surge in airspeed. If your approach is too fast, the surge could push the airspeed above the redline.

Stay out of the "eye" of the vortex. Centrifugal force in the center throws air outward, greatly reducing pressure within the hollow center. The rarified air in the center provides very little lift, and the wall of the hollow center is very turbulent. Further quoting Mr. Swinn,* "A too tight turn on the downwind side put a part of my inside wing into the vortex; the shock threw me into the straps and the wing bent in an alarming manner. This central area of greatly reduced pressure is something to be experienced to be believed. Closely following on this was the shock of hitting the area of greatest uplift just outside the central core. The net result was that the machine was thrown completely out of the column."

If you are 500 feet or more above the ground but having trouble finding lift, the dust devil is well worth a try. If the thermal is sufficiently broad to permit circling within it, you have it made. The dust column may be quite narrow, but this fact does not necessarily mean the thermal is narrow; the thermal may extend beyond the outer limits of visible dust. The way to find out is to try it. Approach the dusty column against the direction of rotation at minimum airspeed. Enter the column near the outer edge of the dust and stay away from the hollow vortex core. Remain alert; you are circling little more than a wing span away from violent turbulence.

Birds and Sailplanes

Soaring birds have an uncanny ability to locate thermals. When birds remain airborne without flapping their wings, they are riding a thermal. A climbing sailplane also shows the pilot's skill in locating thermals. When fishermen are scattered along a river bank or lake shore, the best place to cast your line is near the fisherman who is catching fish. So it is with soaring. Slip in below the successfully soaring aircraft and catch the thermal he is riding or cut in among or below soaring birds.

Wind causes a thermal to lean with altitude. When seeking the thermal supporting soaring birds or aircraft, you must make allowance for the wind. The thermal at lower levels usually is upwind from your high-level visual cue. A thermal may not be continuous from the surface upward to the soaring birds or sailplane; rather it may be in segments or bubbles. If you are unsuccessful in finding the thermal where you expect it, seek elsewhere.

Cumulus Clouds

When convective clouds develop, thermal soaring usually is at its best and the problem of locating thermals is greatly simplified. In chapter 6 we learned that upward moving air expands and cools as it rises. If the air is moist enough, expansional cooling lowers temperature to the dew point; a convective, or cumulus, cloud forms atop the thermal. Cumulus clouds are positive signs of thermals, but thermals grow and die. A cloud grows with a rising thermal; but when the thermal dies, the cloud slowly evaporates. Because the cloud dissipates *after* the thermal ceases, the pilot who can spot the difference between a growing and dying cumulus has enhanced his soaring skill.

The warmest and most rapidly rising air is in the center of the thermal. Therefore, the cloud base will be highest in the center giving a concave shape to the cloud base as shown in the left and center of figure 150. When the thermal ceases, the base assumes a convex shape as shown on the right. Another cue to look for is the outline of the cloud sides and top. Outline of the growing cumulus is firm and sharp. The dying cumulus has fragmentary sides and lacks the definite outline. These outlines are diagrammed also in figure 150. Figure 151 is a photograph of a dying cumulus.

You can expect to find a thermal beneath either of the growing cumuli in figure 150. On the average, the infant cumulus on the left would be the better

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*Ibid., page 80. Mr. Wills' book discusses at length the splendors and perils of dust devil flying by an experienced soaring pilot. It is recommended reading for a greater insight into this special aspect of soaring.

choice because of its longer life expectancy. This is of course playing the probabilities since all cumuli do not grow to the same size.

As a cumulus cloud grows, it may shade the

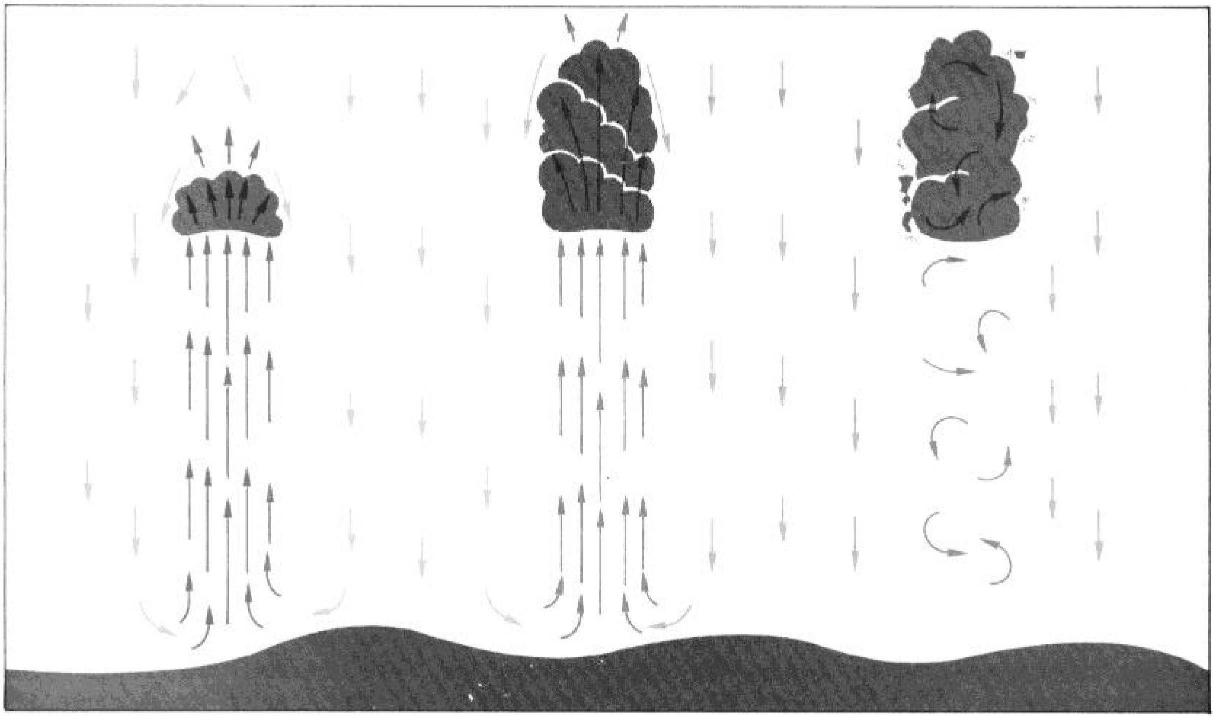

FIGURE 150. Cumulus clouds grow only with active thermals as shown left and center. On the right, the thermal has subsided and the cloud is decaying. Look for a thermal only under a cumulus with a concave base and sharp upper outlines. A cumulus with a convex base or fragmentary outline is dissipating; the thermal under it has subsided. Most often, a cloud just beginning to grow as on the left is the better choice because of its longer life expectancy.

surface that generated it. The surface cools, temporarily arresting the thermal. As the cloud dissipates or drifts away with the wind, the surface again warms and regenerates the thermal. This intermittent heating is one way in which thermals occur as segments or bubbles.

Cloud cover sometimes increases as surface heating increases until much of the sky is covered. Again, surface heating is cut off causing the thermals to weaken or cease entirely. The cloudiness may then decrease. If it is not too late in the day, thermals will regenerate. In the interim period of extensive cloud cover, you may have no choice but to land and wait for the clouds to move on or decrease in coverage.

The clouds may build upward to a high-level inversion and spread out at the base of the inversion to cover much of the sky. Solar heating is cut off and thermals weaken or die. This type of cloudiness can be persistent, often remaining until near sunset, and can halt thermal soaring until another day.

Although abundant convective cloud cover reduces thermal activity, we cannot quote a definite amount that renders thermals too weak for soaring. About 5/10 cover seems to be a good average approximation. Restriction of thermals by cumulus cloudiness first becomes noticeable at low levels. A sailplane may be unable to climb more than a few hundred feet at a low altitude while pilots at higher levels are maintaining height in or just beneath 6/10 to 8/10 convective cloud cover.

Towering Cumulus and Cumulonimbus

When air is highly unstable, the cumulus cloud can grow into a more ambitious towering cumulus or cumulonimbus. These clouds are a different breed. The energy released by copious condensation can increase buoyancy until the thermals become violent (see chs. 6, 7, and 11) . Towering cumulus can produce showers. The cumulonimbus is the thunderstorm cloud producing heavy rain, hail, and icing. Well-developed ***towering cumulus and cumulonimbus are for the experienced pilot only.*** Some pilots find strong lift in or near convective precipitation, but they avoid hail which

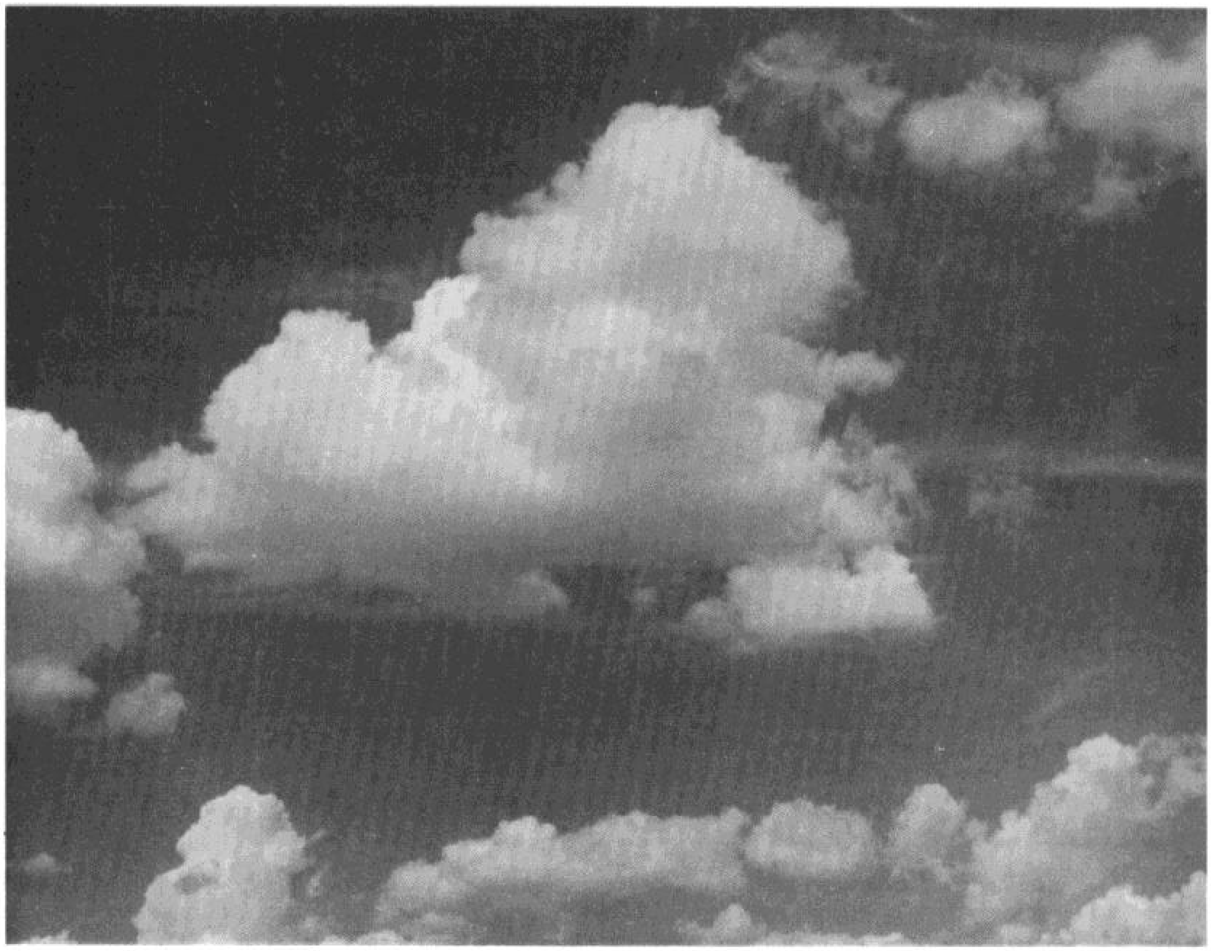

FIGURE 151. Photograph of a dying cumulus. Note the indistinct edges and cloud fragments. The base appears to be convex. One would expect little or no lift beneath this cloud. In contrast, note the top of the cumulus in the lower left corner. Edges are more defined, and a thermal is more likely under this cloud.

can seriously batter the aircraft and ultimately deplete the wallet.

Violent thermals just beneath and within these highly developed clouds often are so strong that they will continue to carry a sailplane upward even with nose down and airspeed at the redline. The unwary pilot may find himself sucked into the cloud. The soaring pilot who inadvertently entered a thunderstorm and returned to tell about it never hankers for a repeat performance.

Middle and High Cloudiness

Dense, broken or overcast middle and high cloudiness shade the surface cutting off surface heating and convective thermals. On a generally warm bright day but with thin or patchy middle or high cloudiness, cumulus may develop, but the thermals are few and weak. The high-level cloudiness may drift by in patches. Thermals may surge and wane as the cloudiness decreases and increases. Never anticipate optimum thermal soaring when plagued by these mid- and high-level clouds.

Altocumulus castellanus clouds, middle-level convective clouds shown in figure 152, develop in updrafts at and just below the cloud levels. They do not extend upward from the surface. If a sailplane can reach levels near the cloud bases, the updrafts with altocumulus castellanus can be used in the same fashion as thermals formed by surface convection. The problem is reaching the convective level.

Wet Ground

Wet ground favors thermals less than dry ground since wet ground heats more slowly (see ch. 2,

FIGURE 152. Altocumulus castellanus clouds are middle level convectiv
layer aloft, and thermals do not extend from the ground upward to t
used for lift if the pilot is able to attain altitude to the base of the unst
stability in the lower levels.

"Heat and Temperature"). Some flat areas with wet soil such as swamps and tidewater areas have reputations for being poor thermal soaring areas. Convective clouds may be abundant but thermals generally are weak.

Showery precipitation from scattered cumulus or cumulonimbus is a sure sign of unstable air favorable for thermals. But when showers have soaked the ground in localized areas, downdrafts are almost certain over these wet surfaces. Avoid shower soaked areas when looking for lift.

So much for locating thermals. A pilot can also enhance his soaring skill by knowing what goes on within a thermal.

THERMAL STRUCTURE

Thermals are as varied as trees in a forest. No two are exactly alike. When surface heating is intense and continuous, a thermal, once begun, continues for a prolonged period in a steady column as in figure 153. Sometimes called the "chimney thermal," this type seems from experience to be most prevalent. In the chimney thermal, lift is available at any altitude below a climbing sailplane or soaring birds.

When heating is slow or intermittent, a "bubble" may be pinched off and forced upward; after an interval ranging from a few minutes to an hour or more, another bubble forms and rises as in figure 154. As explained earlier, intermittent shading by cumulus clouds forming atop a thermal is one reason for the bubble thermal. A sailplane or birds may be climbing in a bubble, but an aircraft attempting to enter the thermal at a lower altitude may find no lift.

A favored theoretical structure of some bubble thermals is the vortex shell which is much like a smoke ring blown upward as diagrammed in figure 155. Lift is strongest in the center of the ring; downdrafts may occur in the edges of the ring or

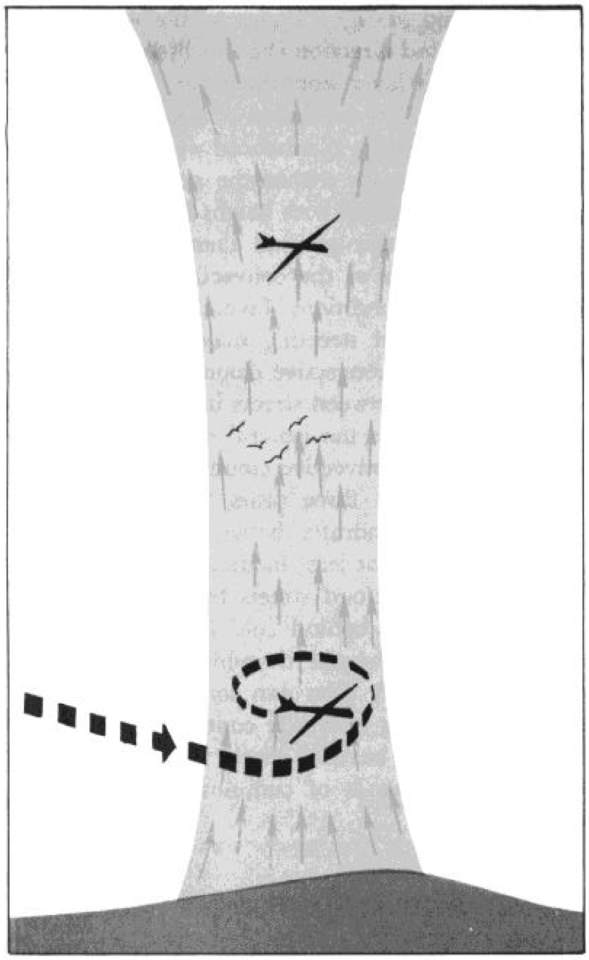

FIGURE 153. Experience indicates that the "chimney" thermal, which is continuous from the ground upward, is the most prevalent type. A sailplane can find lift in such a thermal beneath soaring birds or other soaring aircraft.

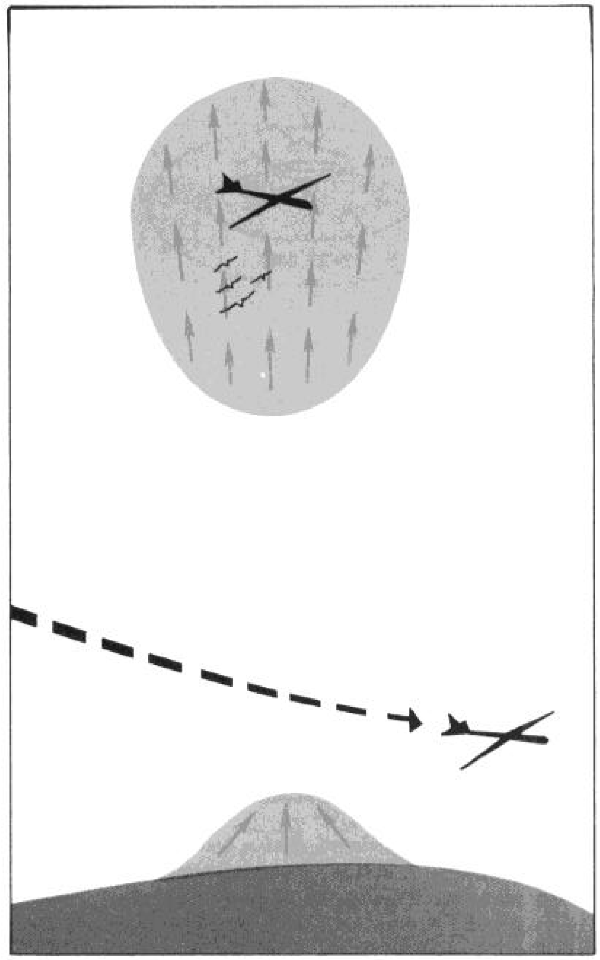

FIGURE 154. Thermals may be intermittent "bubbles." Frequency of the bubbles ranges from a few minutes to an hour or more. A soaring pilot will be disappointed when he seeks lift beneath birds or sailplanes soaring in this type thermal.

shell; and outside the shell, one would expect weak downdrafts.

Wind and Wind Shear

Thermals develop with a calm condition or with light, variable wind. However, it seems that a surface wind of 5 to 10 knots favors more organized thermals.

A surface wind in excess of 10 knots usually means stronger winds aloft resulting in vertical wind shear. This shear causes thermals to lean noticeably. When seeking a thermal under a climbing sailplane and you know or suspect that thermals are leaning in shear, look for lift upwind from the higher aircraft as shown in figure 156.

Effect of shear on thermals depends on the relative strength of the two. Strong thermals can remain fairly well organized with strong vertical wind shear; surface wind may even be at the maximum that will allow a safe launch. Weak thermals are disorganized and ripped to shreds by strong vertical wind shear; individual thermal elements become hard to find and often are too small to use for lift. A shear in excess of 3 knots per thousand feet distorts thermals to the extent that they are difficult to use.

No critical surface wind speed can tell us when to expect such a shear. However, shearing action often is visible in cumulus clouds. A cloud sometimes leans but shows a continuous chimney. At

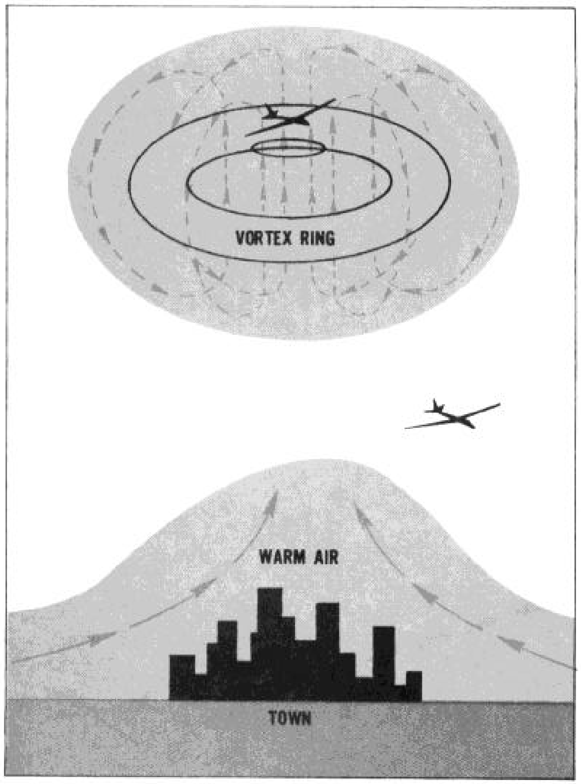

FIGURE 155. It is believed that a bubble thermal sometimes develops a vortex ring resembling a smoke ring blown straight upward. The center of the ring provides excellent lift. A pilot finds only weak lift or possibly sink in the fringes of the ring.

other times, the clouds are completely severed into segments by the shear as in figure 157. Remember, however, that this shearing action is at cloud level; thermals below the clouds may be well organized.

We must not overlook one other vital effect of the low-level wind shear. On final approach for landing, the aircraft is descending into decreasing. Inertia of the aircraft into the decreasing wind causes a drop in airspeed. The decrease in airspeed may result in loss of control and perhaps a stall. The result can be an inelegant landing with possible injury and aircraft damage. A good rule is to add one knot airspeed to normal approach speed for each knot of surface wind.

Thermal Streets

Not infrequently, thermals become organized into "thermal streets." Generally, these streets are parallel to the wind; but on occasion they have been observed at right angles to the wind. They form when wind direction changes little throughout the convective layer and the layer is capped by very stable air. The formation of a broad system of evenly spaced streets is enhanced when wind speed reaches a maximum within the convective layer; that is, wind increases with height from the surface upward to a maximum and then decreases with height to the top of the convective layer. Figure 158 diagrams conditions favorable for thermal. Thermal streeting may occur either in clear air or with convective clouds.

The distance between streets in such a system is two to three times the general depth of the convective layer. If convective clouds are present, this distance is two to three times the height of the cloud tops. Downdrafts between these thermal streets are usually at least moderate and sometimes strong. Cumulus cloud streets frequently form in the United States behind cold fronts in the cold air of polar outbreaks in which relatively flat cumuli develop. A pilot can soar under a cloud street maintaining generally continuous flight and seldom, if ever, have to circle. Figure 159 is a photograph of bands of cumulus clouds marking thermal streets.

HEIGHT AND STRENGTH OF THERMALS

Since thermals are a product of instability, height of thermals depends on the depth of the unstable layer, and their strength depends on the degree of instability. If the idea of instability is not clear to you, now is the time to review chapter 6.

Most likely you will be soaring from an airport with considerable soaring activity—possibly the home base of a soaring club—and you are interested in a soaring forecast. Your airport may have an established source of a daily soaring weather forecast from the National Weather Service. If conditions are at all favorable for soaring, you will be specifically interested in the earliest time soaring can begin, how high the thermals will be, strength of the thermals, cloud amounts—both convective and higher cloudiness—visibility at the surface and at soaring altitudes, probability of showers, and winds both at the surface and aloft. The forecast may include such items as the thermal index (TI), the maximum temperature forecast, and the depth of the convective layer.

Many of these parameters the forecaster determines from upper air soundings plotted on a

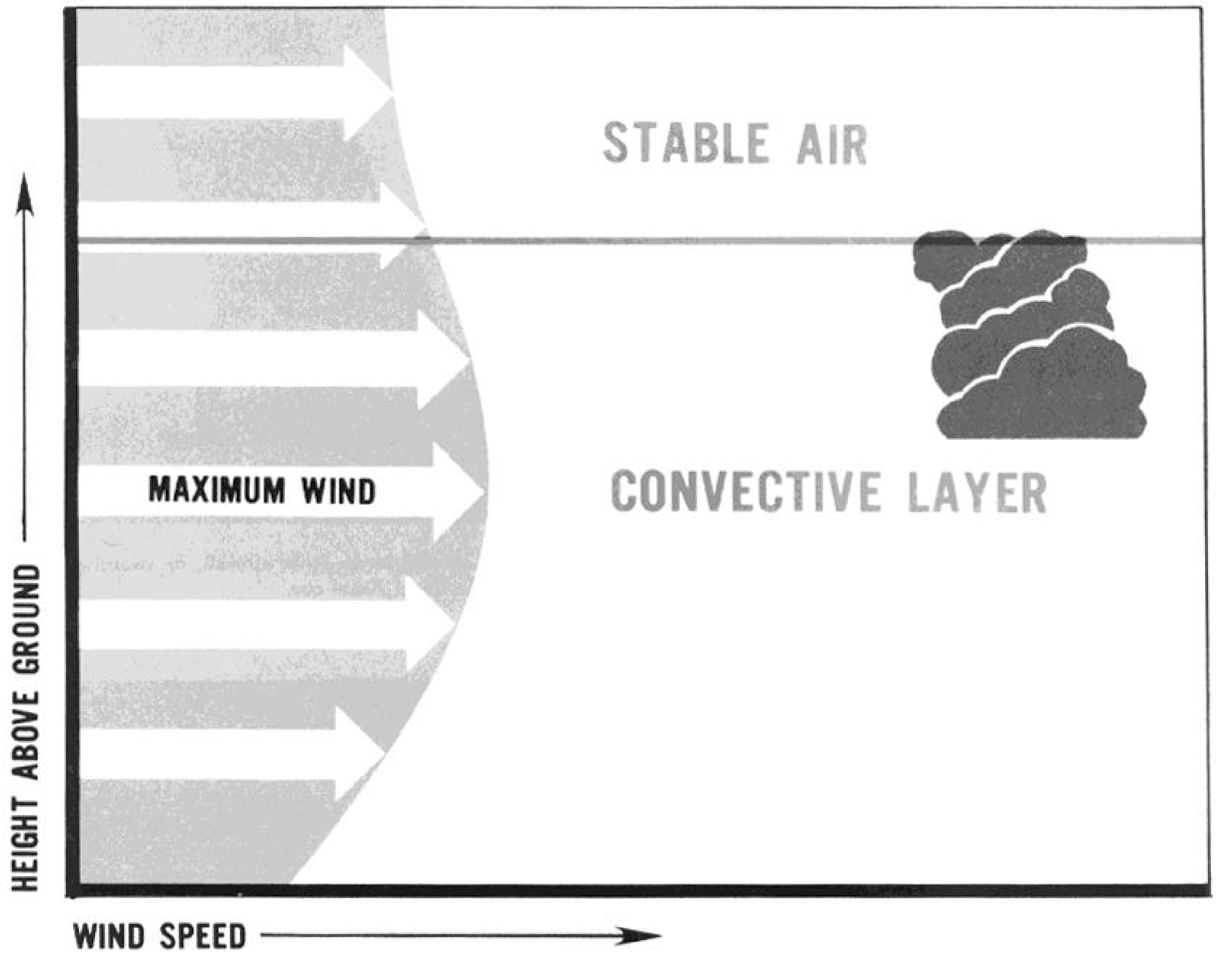

FIGURE 158. Conditions favorable for thermal streeting. A very stable layer caps the convective layer, and wind reaches a maximum within the convective layer. If cumulus clouds mark thermal streets, the top of the convective layer is about the height of the cloud tops.

FIGURE 159. Cumulus clouds in thermal streets photographed from a satellite by a high resolution camera. (Courtesy the National Environmental Satellite Service.)

pseudo-adiabatic chart. If you become familiar with this chart, you can better grasp the meanings of some of these forecast parameters; and you may try a little forecasting on your own.

The Pseudo-Adiabatic Chart

The pseudo-adiabatic chart is used to graphically compute adiabatic changes in vertically moving air and to determine stability. It has five sets of lines shown in figure 160. These lines are:

1. Pressure in millibars (horizontal lines),
2. Temperature in degrees Celsius (vertical lines),
3. Dry adiabats (sloping black lines),
4. Lines of constant water vapor or mixing ratio* (solid red lines), and
5. Moist adiabats (dashed red lines).

The chart also has an altitude scale in thousands of feet along the right margin and a Fahrenheit temperature scale across the bottom.

You might like to get one of these charts from a National Weather Service Office. The chart used in actual practice has a much finer grid than the one shown in figure 160. You can cover the chart with acetate and check examples given here along with others you can develop yourself. This procedure can greatly enhance your feel for processes occurring in a vertically moving atmosphere.

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*Ratio of water vapor to dry air.

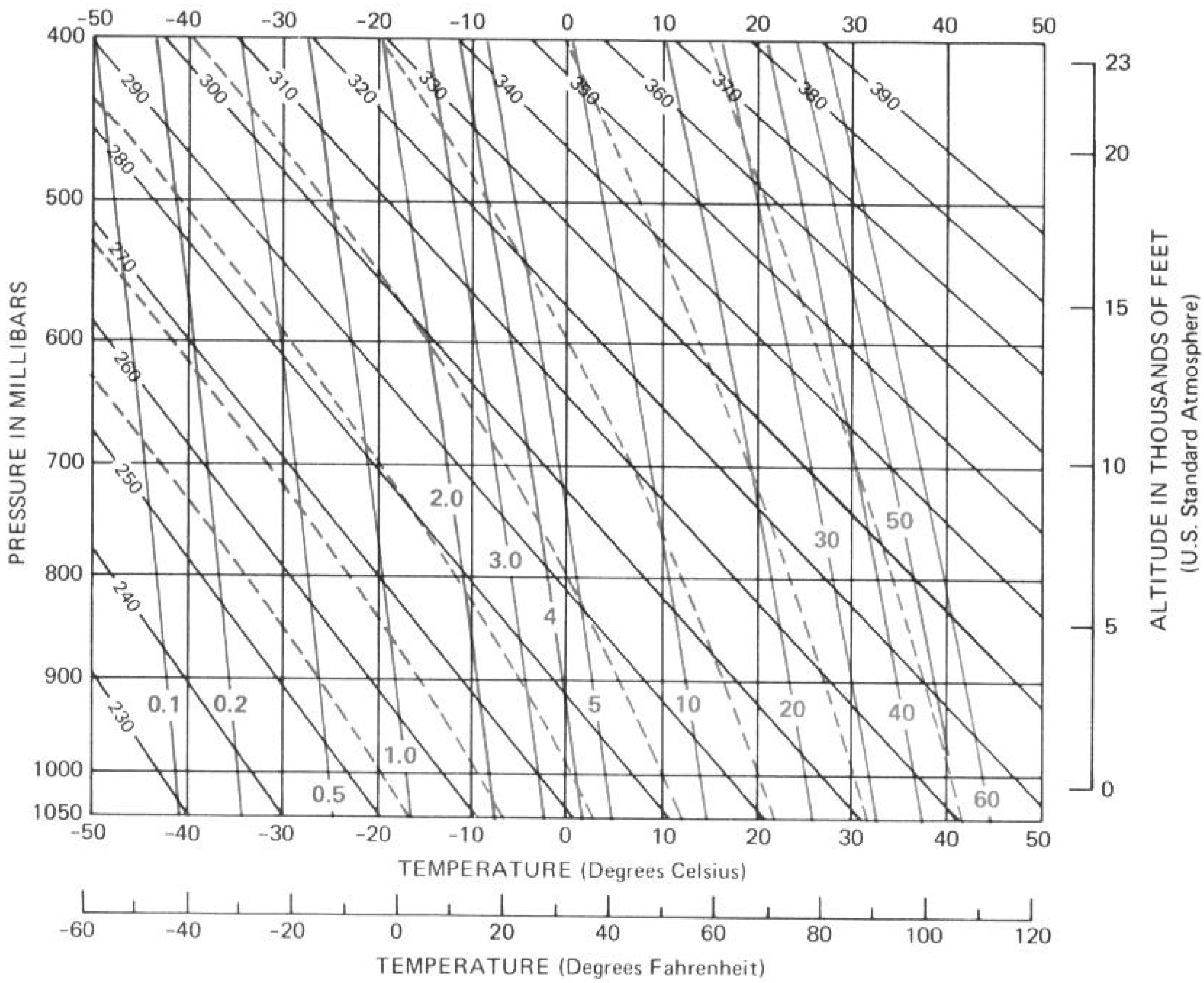

FIGURE 160. The Pseudo-Adiabatic Chart. Horizontal lines are pressure; vertical lines, temperature; sloping lines, dry adiabats graphing the rate of dry adiabatic cooling. Solid red lines are constant mixing ratio, and dashed red lines are moist adiabats graphing the saturated rate of cooling. Since red lines apply only to moist adiabatic changes, they are omitted from subsequent examples.

Examples shown here deal with dry thermals; and since the red lines in figure 160 concern moist adiabatic changes, they are omitted from the examples. If you care to delve deeper into use of the chart, you will find moist adiabatic processes even more intriguing than dry processes.

Plotted Sounding

An upper air observation, or sounding, is plotted on the pseudo-adiabatic chart as shown by the heavy, solid black line in figure 161. This plotting is the vertical temperature profile at the time the radiosonde observation was taken. It is the actual or existing lapse rate (see ch. 6). Blue lines are added to the illustration showing appropriate altitudes to aid you in interpreting the chart.

Depth of Convective layer (Height of Thermals)

We know that for air to be unstable, the existing lapse rate must be equal to or greater than the dry adiabatic rate of cooling. In other words, in figure

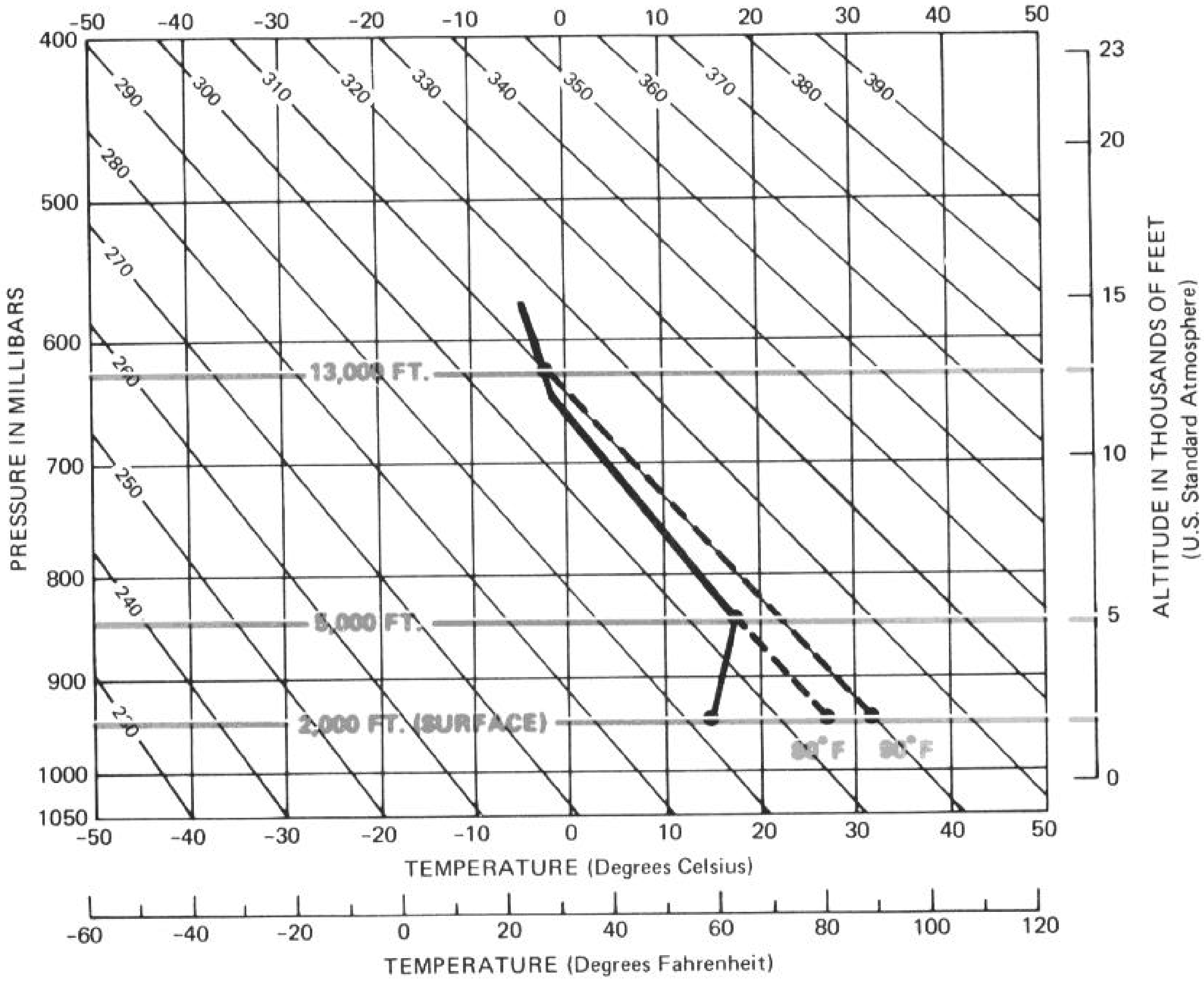

FIGURE 161. An early morning upper air observation plotted on the pseudo-adiabatic chart. The solid black line is the vertical temperature profile or existing lapse rate from the surface to about 15,000 feet ASL. Blue altitude lines are projected across the chart from the altitude scale on the right to aid in interpretation. If thermals are to develop, the lapse rate must become equal to or greater than the dry adiabatic rate of cooling—that is, the line representing the lapse rate must slope parallel to or slope more than the dry adiabats. Since it does not, the air in the early morning was stable. By the time the surface temperature reached 80° F, convection occurred to 5,000 feet; the existing lapse rate then was parallel to the dry adiabat following the dashed line from the surface to 5,000 feet; the air was unstable in the lower levels. By the time the temperature reached the afternoon maximum of 90° F, the air was unstable to 13,000 feet; the existing lapse rate in the heat of the day was dry adiabatic and the air unstable to 13,000 feet ASL. This is the maximum height you could expect thermals on this particular day.

161, the solid black line representing the plotted existing lapse rate would slope parallel to or slope more than the dry adiabats. Obviously it does not. Therefore, at the time the sounding was taken, the air was stable; there was no convective or unstable layer, and thermals were nonexistent. Thermal soaring was impossible.

Now assume that the sounding was made about the time of sunrise. Surface temperature was 59° F (15° C) . As temperature rises near the surface during the day, air in the lower levels is warmed and forced upward, cooling at the dry adiabatic rate. Convection begins in the lowest levels. By the time the surface temperature reaches 80° F (about 27° C), convection lifts the air to the level at which it cools adiabatically to the temperature of the surrounding air at 5,000 feet. The existing lapse rate now becomes dry adiabatic from the surface to 5,000 feet and follows the dashed line from the surface to that level. Surface elevation is 2,000 feet ASL; so the convective layer is now 3,000 feet deep. Thermals exist to 3,000 feet above the surface, and low-level soaring is now possible. Above 5,000 feet the lapse rate still is essentially unchanged from the initial lapse rate.

Maximum Height of Thermals

Let's further assume that maximum temperature forecast for the day is 90° F (about 30° C). Plot 90° F at the surface elevation and draw a line (the dashed black line) parallel to the dry adiabats to the level at which it intersects the early morning sounding. This level is 13,000 feet ASL. The convective layer at time of maximum heating would be 11,000 feet deep and soaring should be possible to 13,000 feet ASL. The existing lapse rate in the heat of the day would follow the dashed line from the surface to 13,000 feet; above 13,000, the lapse rate would remain essentially unchanged.

Remember that we are talking about dry thermals. If convective clouds form below the indicated maximum thermal height, they will greatly distort the picture. However, if cumulus clouds do develop, thermals below the cloud base should be strengthened. If more higher clouds develop than were forecast, they will curtail surface heating, and most likely the maximum temperature will be cooler than forecast. Thermals will be weaker and will not reach as high an altitude.

Thermal Index (TI)

Since thermals depend on sinking cold air forcing warm air upward, strength of thermals depends on the temperature difference between the sinking air and the rising air—the greater the temperature difference the stronger the thermals. To arrive at an approximation of this difference, the forecaster computes a thermal index (TI).

A thermal index may be computed for any level; but ordinarily, indices are computed for the 850 and 700-millibar levels, or about 5,000 and 10,000 feet respectively. These levels are selected because they are in the altitude domain of routine soaring and because temperature data are routinely available for these two levels.

Three temperature values are needed—the observed 850-millibar and 700-millibar temperatures and the forecast maximum temperature. Let's assume a sounding as in figure 162 with an 850 millibar temperature of 15° C, a 700-millibar temperature of 10° C, and forecast maximum of 86° F (30° C) . Plot the three temperatures using care to place the maximum temperature plot at field elevation (2,000 feet in figure 162). Now draw a line (the black dashed line) through the maximum temperature parallel to the dry adiabats. Note that the dashed line intersects the 850-millibar level at 20° C and the 700-millibar level at 4° C. Algebraically subtract these temperatures from actual sounding temperatures at corresponding levels. Note the difference is —5° C at 850 millibars (15—20 =—5) and +6 at 700 millibars (10— 4= +6). These values are the TI's at the two levels.

Strength of thermals is proportional to the magnitude of the negative value of the TI. A TI of—8 or—10 predicts very good lift and a long soaring day. Thermals with this high a negative value will be strong enough to hold together even on a windy day. A TI of—3 indicates a very good chance of sailplanes reaching the altitude of this temperature difference. A TI of—2 to zero leaves much doubt; and a positive TI offers even less hope of thermals reaching the altitude. Remember that the TI is a forecast value. A miss in the forecast maximum or a change in temperature aloft can alter the picture considerably. The example in figure 162 should promise fairly strong thermals to above 5,000 feet but no thermals to 10,000.

Figure 163 is another example showing an early morning sounding with a 3,000-foot surface temperature of 10° C (50° F), an 850-millibar temperature of 15° C, a 700-millibar temperature of

3° C, and a forecast maximum of 86° F (30° C). What are the TI's at 850 and 700 millibars? Would you expect thermals to 850 millibars? Would they

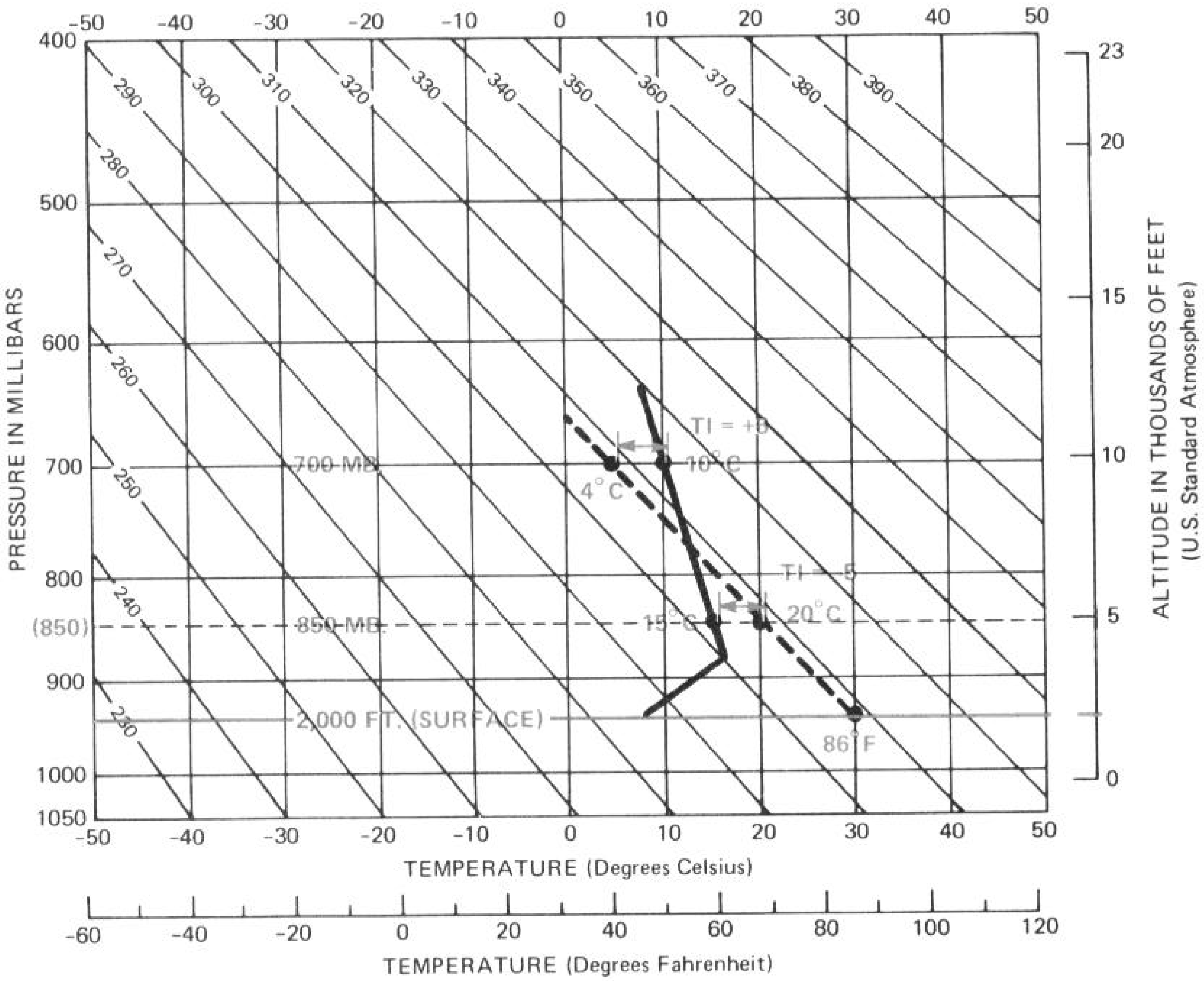

FIGURE 162. Computing the thermal index (TI). From an early morning upper air observation, obtain the 850-millibar and 700-millibar temperatures—15° C and 10° C respectively, in this example. Obtain a forecast maximum temperature, 86° F, and plot it at the surface elevation. Draw a dry adiabat, the dashed line, upward through the 700-millibar level. This dry adiabat is the temperature profile of a rising column of air. To find the TI at any level, subtract the temperature of the rising column at that level from the temperature of the original sounding at the same level. The TI at 850 millibars is −5 (15 − 20 = −5). At 700 millibars, the TI is +6 (10 − 4 = +6).

be moderate, strong, or weak? How about at 700 millibars? What is the maximum altitude you would expect thermals to reach? *Answers:* 850 millibar TI, —8; 700-millibar TI, —5; thermals would reach both levels, strong at 850, moderate at 700; maximum altitude of thermals, about 16,000 feet ASL.

Often the National Weather Service will have no upper air sounding taken near a soaring base. Forecasts must be based on a simulated sounding derived from distant observations. At other times, for some reason a forecast may not be available. Furthermore, you can often augment the forecast with local observations. You are never at a complete loss to apply some of the techniques just described.

Do It Yourself

The first step in determining height and strength of thermals is to obtain a local sounding. How do you get a local sounding? Send your tow aircraft aloft about sunrise and simply read outside air temperatures from the aircraft thermometer and altitudes from the altimeter. Read temperatures at 500-foot intervals for about the first 2,000 feet and at 1,000-foot intervals at higher altitudes. The information may be radioed back to the ground, or

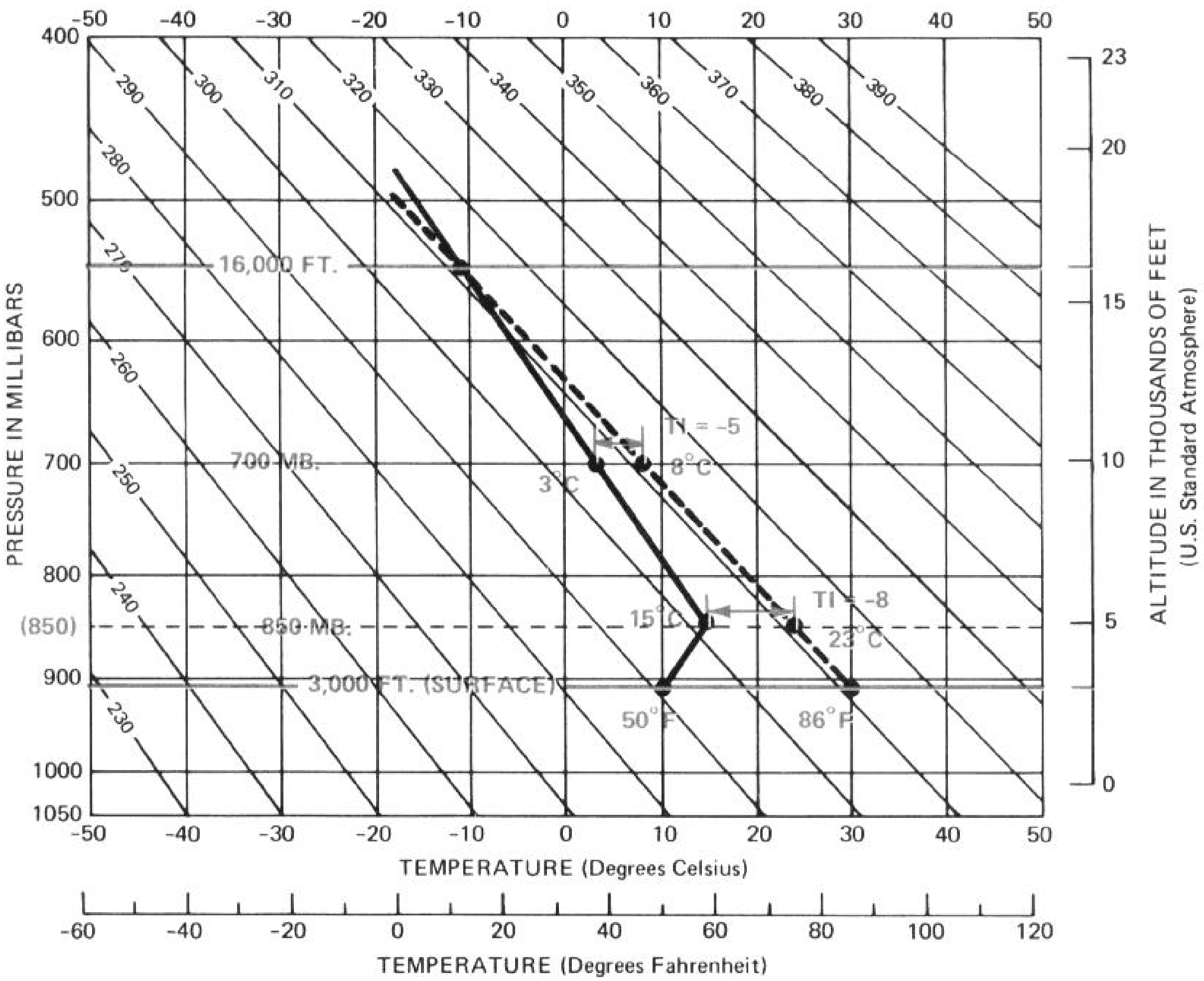

FIGURE 163. Another example of computing TI's and maximum height of thermals. See discussion in caption of figure 162. By the time of maximum heating, excellent lift should be available in lower levels and moderate lift above 10,000 feet. Although thermals should continue to 16,000 feet, you could expect weak lift above 12,000 or 13,000 feet because of the small difference between temperatures in the thermal and in the surrounding air.

may be recorded in flight and analyzed after landing. When using the latter method, read temperatures on both ascent and descent and average the temperatures at each level. This type of sounding is an airplane observation or APOB. Plot the sounding on the pseudo-adiabatic chart using the altitude scale rather than the pressure scale.

Next we need a forecast maximum temperature. Perhaps you can pick up this forecast temperature from the local forecast. If not, you can use your best judgment comparing today's weather with yesterday's.

Following is an APOB as taken by the tow aircraft from an airport elevation of 1,000 feet ASL:

Alt.	Temperatures °C Ascent	Descent	Avg.
1000	17	19	18
1500	15	17	16
2000	20	20	20
2500	22	24	23
3000	22	22	22
4000	20	18	19
5000	18	18	18
6000	16	14	15
7000	13	13	13
8000	9	9	9
9000	7	5	6
10000	5	3	4
11000	1	1	1
12000	−3	−1	−2
13000	−5	−5	−5
14000	−6	−6	−6
15000	−7	..	−7

Plot the APOB on the pseudo-adiabatic chart using the average temperatures from the last column. Figure 164 shows the plotted APOB.

Next we need a forecast maximum temperature. Let's assume that a local forecast is not available and that weather today is essentially the same as it was yesterday. Yesterday's maximum was 95° F (35° C), so let's use the same maximum for today. We should not be too far wrong. Plot the maximum as shown and proceed to compute TI's and maximum height of thermals. Since our temperature data are for indicated altitudes rather than pressure levels, let's compute TI's for 5,000 feet and 10,000 feet rather than for pressure levels. What do you get for a TI at 5,000 feet? At 10,000 feet? What is the anticipated maximum altitude of thermals? *Answers:* TI at 5,000 feet,—4; TI at 10,000 feet, —3; maximum altitude of thermals, 14,000 feet.

Although these procedures are primarily for dry thermals, they work reasonably well for thermals below the bases of convective clouds.

Convective Cloud Bases

Soaring experience suggests a shallow, stable layer immediately below the general level of convective cloud bases through which it is difficult to soar. This layer is 200 to 600 feet thick and is known as the *sub-cloud layer.* The layer appears to act as a filter allowing only the strongest ther-

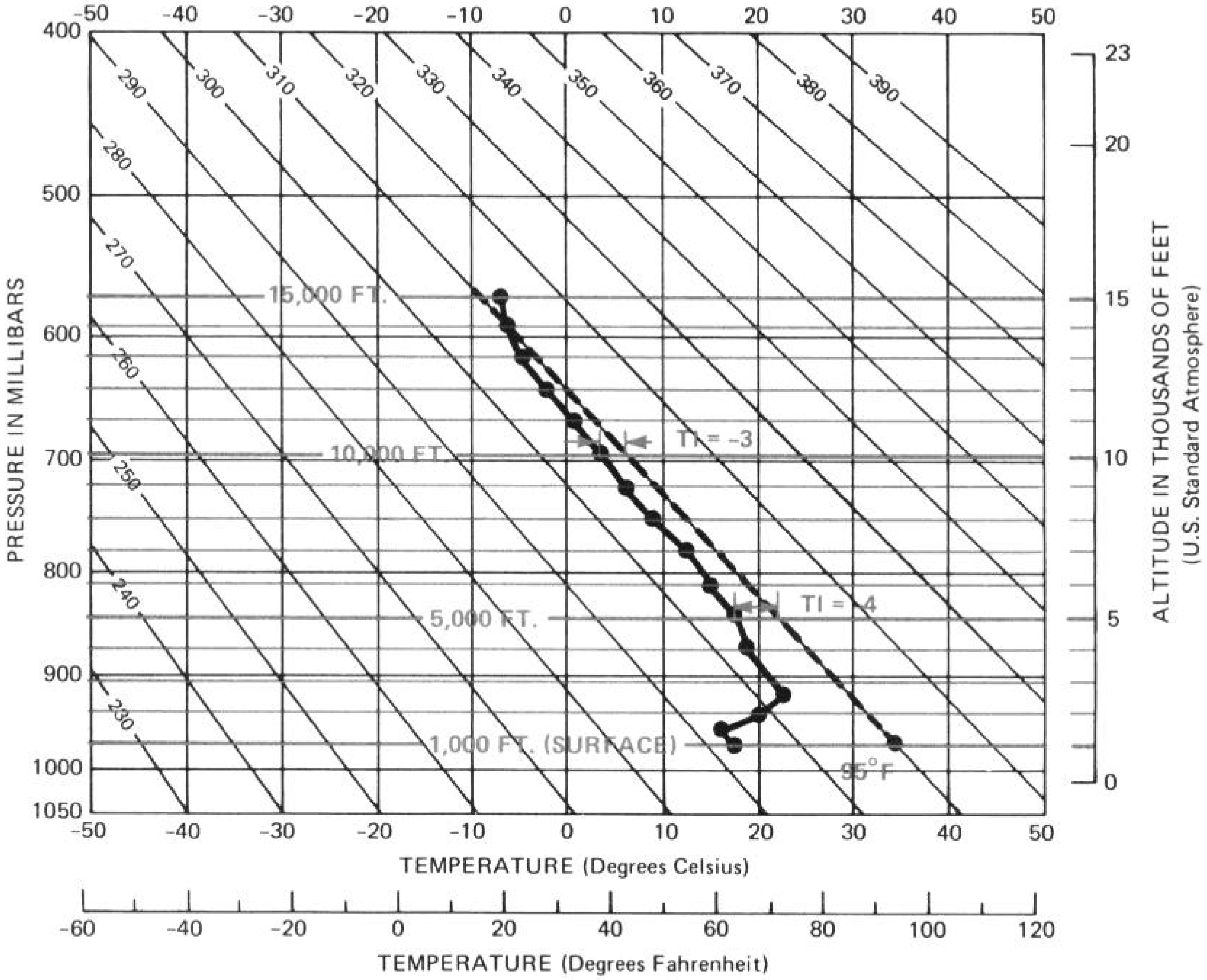

FIGURE 164. An upper air observation made from an aircraft called an airplane observation or APOB. Maximum height of thermals and TI's are computed the same as in preceding examples except that TI's are for indicated altitudes instead of pressure levels. The APOB may be used in lieu of or as a supplement to the forecast.

mals to penetrate it and form convective clouds. Strongest thermals are beneath developing cumulus clouds.

Thermals intensify within a convective cloud; but evaporation cools the outer edges of the cloud causing a downdraft immediately surrounding it. Add to this the fact that downdrafts predominate between cumulus clouds, and you can see the slim chance of finding lift between clouds above the level of the cloud base. In general, thermal soaring during convective cloud activity is practical only at levels below the cloud base.

In chapter 6, we learned to estimate height in thousands of feet of a convective cloud base by dividing the surface temperature-dew point spread by 4. If the rising column were self-contained—that is, if no air were drawn into the sides of the thermal—the method would give a fairly accurate height of the base. However, this is not the case. Air ~s entrained or drawn into the sides of the thermal; and this entrained air lowers the water vapor content of the thermal allowing it to reach a somewhat higher level before condensation occurs. Bases of the clouds are generally 10 to 15 percent higher than the computed height.

Entrainment is a sticky problem; observers and forecasters can only estimate its effect. Until a positive technique is developed, heights of cumulus bases will tend to be reported and forecast too low. Currently, in the eastern United States, cumulus bases are seldom reported above 6,000 feet when the base may actually be 7,000 or 8,000 feet. In the western part of the country, cumulus bases have been observed by aircraft at 12,000 to 14,000 feet above the ground but seldom are reported above 10,000 feet.

CROSS-COUNTRY THERMAL SOARING

A pilot can soar cross-country using either isolated thermals or thermal streets. When using isolated thermals, he gains altitude circling in thermals and then proceeds toward the next thermal in the general direction of his cross-country. Under a thermal street, he may be able to proceed with little if any circling if his chosen course parallels the thermal streets. It goes without saying that he can obtain the greatest distance by flying in the direction of the wind.

In the central and eastern United States, the most favorable weather for cross-country soaring occurs behind a cold front. Lindsay* has found that about 82 percent of thermal cross-countries in these areas were made after a cold front had passed and ahead of the following high pressure center. Four factors contribute to making this pattern ideal. (1) The cold polar air is usually dry, and thermals can build to relatively high altitudes. (2) The polar air is colder than the ground; and thus, the warm ground aids solar radiation in heating the air. Thermals begin earlier in the morning and last later in the evening. On occasions, soarable lift has been found at night. (3) Quite often, colder air at high altitudes moves over the cold, low-level outbreak intensifying the instability and strengthening the thermals. (4) The wind profile frequently favors thermal streeting—a real boon to speed and distance.

The same four factors may occur with cold frontal passages over mountainous regions in the western United States. However, rugged mountains break up the circulation; and homogeneous conditions extend over smaller areas than over the eastern parts of the country. The western mountain regions and particularly the desert southwest have one decided advantage. Air is predominantly dry with more abundant daytime thermal activity favoring cross-country soaring although it may be for shorter distances.

Among the world's most favorable tracks for long distance soaring is a high plains corridor along the east slope of the Rocky Mountains stretching from southwest Texas to Canada.** Many crosscountry records have been set in this corridor. Southwest Texas is the chosen site for many national and international soaring meets. Terrain in the corridor is relatively flat and high with few trees; terrain surface ranges from barren to short grass. These surface features favor strong thermal activity. Prevailing wind is southerly and moderately strong giving an added boost to northbound cross-countries.

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*Charles V. Lindsay. "Types of Weather Favoring Cross-Country Soaring " '*Soaring*, December 1964, pp. 6-9.

** For an in-depth discussion of this area, see "Thermal Soaring—Southwest Style," by David H Owens, *Soaring*, May 1966, pp. 1~12.

FRONTAL SOARING

Warm air forced upward over cold air above a frontal surface can provide lift for soaring. However, good frontal lift is transitory, and it accounts for a very small portion of powerless flight. Seldom will you find a front parallel to your desired crosscountry route, and seldom will it stay in position long enough to complete a flight. A slowly moving front provides only weak lift. A fast moving front often plagues the soaring pilot with cloudiness and turbulence.

A front can on occasion provide excellent lift for a short period. You may on a cross-country be riding wave or ridge lift and need to move over a flat area to take advantage of thermals. A front may offer lift during your transition.

Fronts often are marked by a change in cloud type or amount. However, the very presence of clouds may deter you from the front. Spotting a dry front is difficult. Knowing that a front is in the vicinity and studying your aircraft reaction can tell you when you are in the frontal lift. Staying in the lift is another problem. Observing ground indicators of surface wind helps.

An approaching front may enhance thermal or hill soaring. An approaching front or a frontal passage most likely will disrupt a sea breeze or mountain wave. Post frontal thermals in cold air were discussed earlier.

SEA BREEZE SOARING

In many coastal areas during the warm seasons, a pleasant breeze from the sea occurs almost daily. Caused by the heating of land on warm, sunny days, the sea breeze usually begins during early forenoon, reaches a maximum during the afternoon, and subsides around dusk after the land has cooled. The leading edge of the cool sea breeze forces warmer air inland to rise as shown in figure 165. Rising air from over land returns seaward at higher altitude to complete the convective cell.

A sailplane pilot operating in or near coastal areas often can find lift generated by this convective circulation. The transition zone between the cool, moist air from the sea and the warm, drier air inland is often narrow and is a shallow, ephemeral kind of pseudo-cold front.

SEA BREEZE FRONT

Sometimes the wedge of cool air is called a sea breeze front. If sufficient moisture is present, a line of cumuliform clouds just inland may mark the front. Whether marked by clouds or not, the upward moving air at the sea breeze front occasionally is strong enough to support soaring flight. Within the sea breeze, i.e., between the sea breeze front and the ocean, the air is usually stable, and normally, no lift may be expected at lower levels. However, once airborne, pilots occasionally have found lift at higher levels in the return flow aloft. A visual indication of this lift is cumulus extending seaward from the sea breeze front.

The properties of a sea breeze front and the extent of its penetration inland depend on factors such as the difference in land and sea water temperatures, general wind flow, moisture, and terrain.

Land vs Sea Water Temperature

A large difference in land and sea water temperature intensifies the convective cell generating a sea breeze. Where coastal waters are quite cool, such as along the California coast, and land temperatures warm rapidly in the daytime, the sea breeze becomes pronounced, penetrating perhaps 50 to 75 miles inland at times. Copious sunshine and cool sea waters favor a well-developed sea breeze front.

Strength and Direction of General Wind

The sea breeze is a local effect. Strong pressure gradients with a well-developed pressure system can overpower the sea breeze effect. Winds will follow the direction and speed dictated by the strong pressure gradient. Therefore, a sea breeze front is most likely when pressure gradient is weak and wind is light.

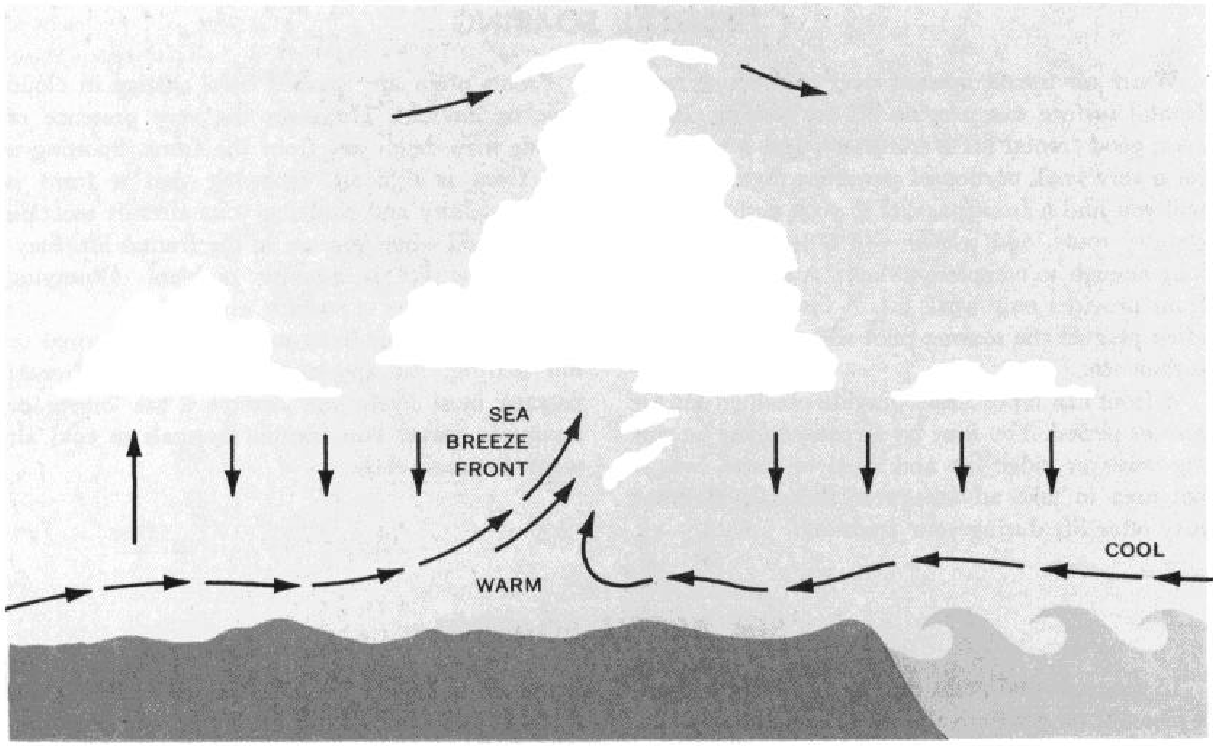

FIGURE 165. Schematic cross section through a sea breeze front. If the air inland is moist, cumulus often marks the front.

Moisture

When convection is very deep, the frontal effect of a sea breeze may sometimes trigger cumulonimbus clouds provided the lifted air over land contains sufficient moisture. More often, the cumulus are of limited vertical extent. Over vegetation where air is usually moist, sea breeze cumulus are the rule. Over arid regions, little or no cumulus development may be anticipated with a sea breeze front.

Terrain

Irregular or rough terrain in a coastal area may amplify the sea breeze front and cause convergence lines of sea breezes originating from different areas. Southern California and parts of the Hawaiian Islands are favorable for sea breeze soaring because orographic lift is added to the frontal convection. Sea breezes occasionally may extend to the leeward sides of hills and mountains unless the ranges are high and long without abrupt breaks. In either case, the sea breeze front converges on the windward slopes, and upslope winds augment the convection. Where terrain is fairly flat, sea breezes may

penetrate inland for surprising distances but with weaker lift along the sea breeze front. In the Tropics, sea breezes sometimes penetrate as much as 150 miles inland, while an average of closer to 50 miles inland is more usual in middle latitudes. Sea breezes reaching speeds of 15 to 25 knots **are** not uncommon.

VISUAL CLUES

When a sea breeze front develops, visual observations may provide clues to the extent of lift that you may anticipate, viz.:

1. Expect little or no lift on the seaward side of the front when the sea air is markedly void of convective clouds or when the sea breeze spreads low stratus inland. However, some lift may be present along the leading edge of the sea breeze or just ahead of it.
2. Expect little or no lift on the seaward side of the front when visibility decreases markedly in the

sea breeze air. This is an indicator of stable air within the sea breeze.

3. A favorable visual indication of lift along the sea breeze front is a line of cumulus clouds marking the front; cumuli between

the sea breeze front and the ocean also indicate possible lift within the sea breeze air, especially at higher levels. Cumulus bases in the moist sea air often are lower than along the front.

4. When a sea breeze front is void of cumulus but converging streamers of dust or smoke are observed, expect convection and lift along the sea breeze front.
5. Probably the best combination to be sighted is cumuli and converging dust or smoke plumes along the sea breeze front as it moves upslope over hills or mountains. The upward motion is amplified by the upslope winds.
6. A difference in visibility between the sea air and the inland air often is a visual clue to the leading edge of the sea breeze. Visibility in the sea air may be restricted by haze while visibility inland is unrestricted. On the other hand, the sea air may be quite clear while visibility inland is restricted by dust or smoke.

LOCAL SEA BREEZE EXPLORATIONS

Unfortunately, a sea breeze front is not always easy to find, and it is likely that many an opportunity for sea breeze soaring goes unnoticed. As yet, little experience has been accrued in locating a belt of sea breeze lift without visual clues such as clouds, haze, or converging smoke or dust plumes. As the sport of soaring grows, so will the knowledge of sea breeze soaring expand and the peculiarities of more local areas come to light. In the United States, the area where the most experience probably has been gained is over the southern California high desert where the sea breeze moves eastward over the Los Angeles Coastal Plain into the Mojave Desert.

Los Angeles "Smoke Front"

The sea breeze front moving from the Los Angeles coastal plain into the Mojave Desert has been dubbed the "Smoke Front." It has intense thermal activity and offers excellent lift along the leading edge of the front. Associated with the sea breeze

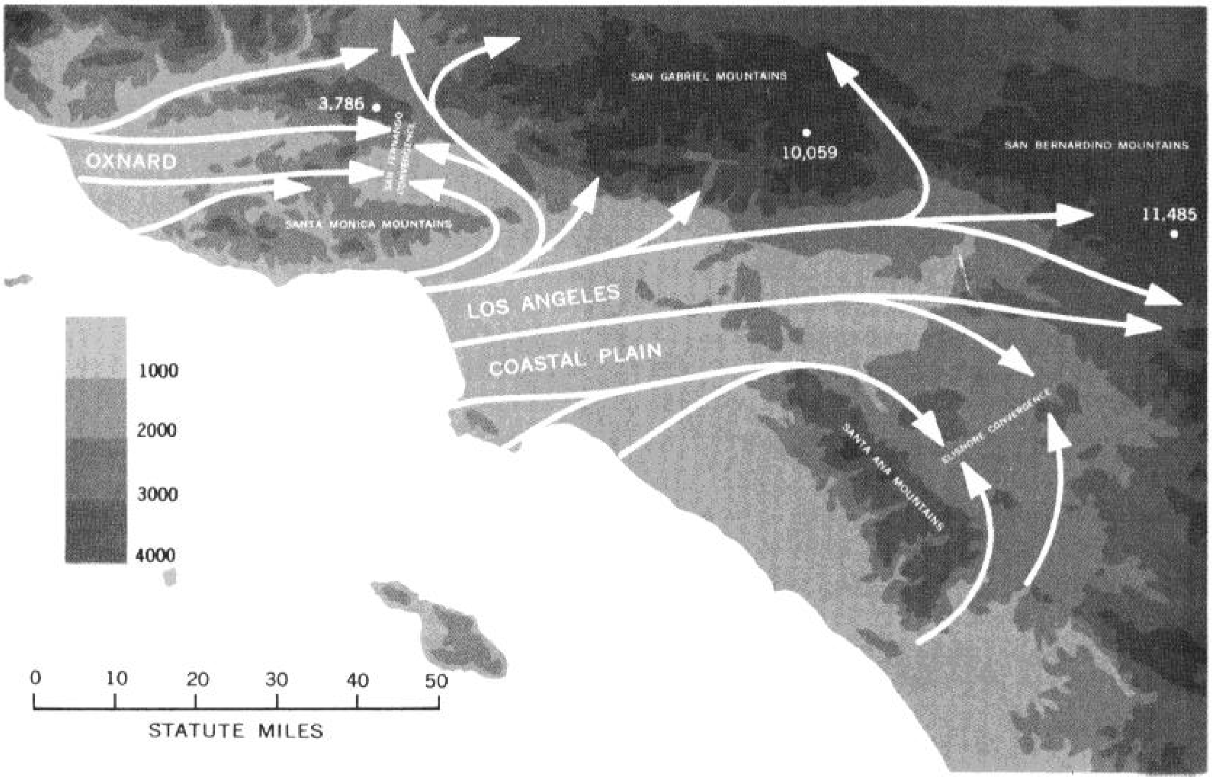

FIGURE 166. Sea breeze flow into the San Fernando Valley. Note the San Fernando convergence zone, upper left, and the Elsinore convergence zone, lower right.

that moves inland over the Los Angeles coastal plain are two important zones of convergence, shown in figure 166. Sea breezes of different origin meet in the convergence zones producing vertical currents capable of supporting sailplanes. One convergence line is the "San Fernando Convergence Zone;" a larger scale zone is in the Elsinore area, also shown in figure 166. This convergence zone apparently generates strong vertical currents since soaring pilots fly back and forth across the valley along the line separating smoky air to the north from relatively clear air to the south. Altitudes reached depend upon the stability, but usually fall within the 6,000 feet to 12,000 feet ASL range for the usual dry thermal type lift. Seaward, little or no lift is experienced in the sea breeze air marked by poor visibility.

Cape Cod Peninsula

Figure 167 shows converging air between sea breezes flowing inland from opposite coasts of the Cape Cod Peninsula. Later in the development of the converging sea breezes, the onset of convection is indicated by cumulus over the peninsula. Sailplane pilots flying over this area as well as over Long Island, New York, have found good lift in the convergence lines caused by sea breezes blowing inland from both coasts of the narrow land strips.

Great Lakes Area

Sea breeze fronts have been observed along the shore lines of the Great Lakes. Weather satellites have also photographed this sea breeze effect on the western shore of Lake Michigan. It is quite likely that conditions favorable for soaring occur at times.

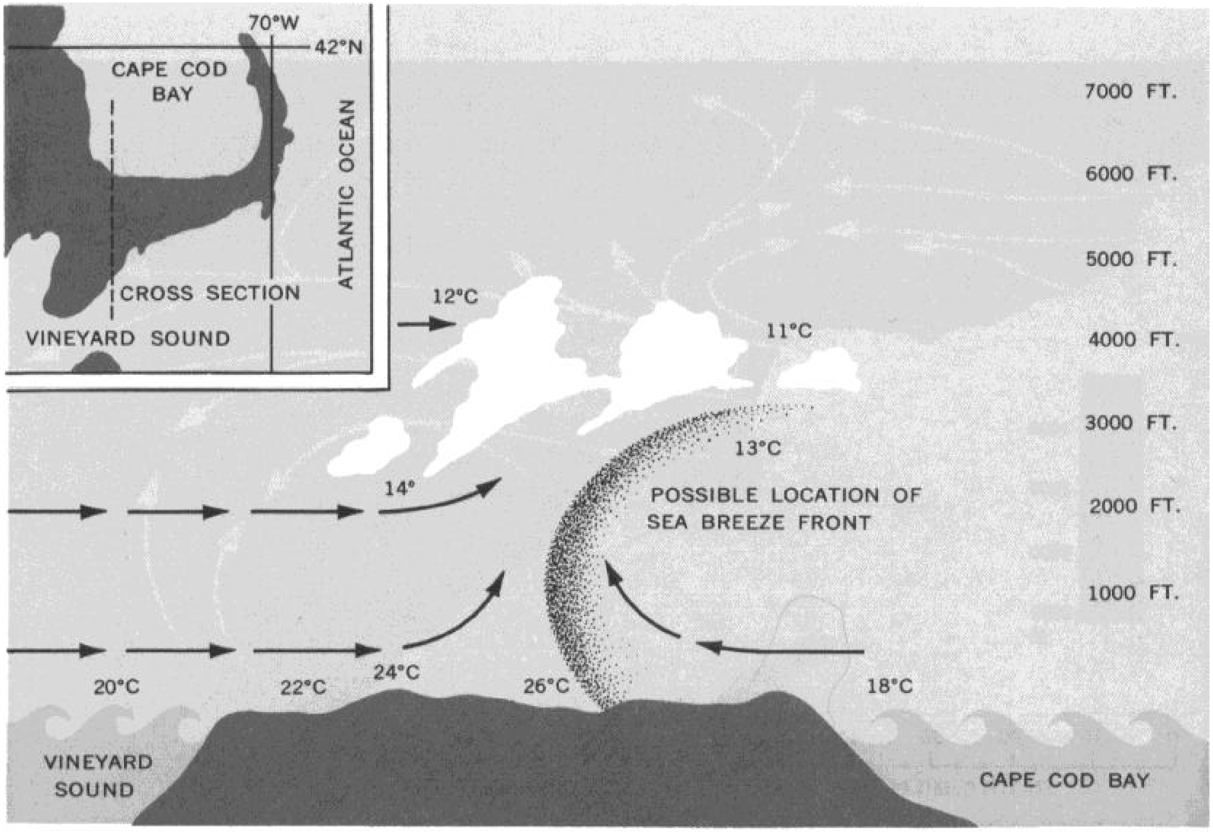

FIGURE 167. Sea breeze convergence zone, Cape Cod, Massachusetts. Sea breezes from opposite coasts converge over the cape.

RIDGE OR HILL SOARING

Wind blowing toward hills or ridges flows upward, over, and around the abrupt rises in terrain. The upward moving air creates lift which is sometimes excellent for soaring. Figure 168 is a schematic showing area of best lift. Ridge or hill soaring offers great sport to the sailplane pilot who accepts the challenge and can wait for proper wind and stability combinations.

WIND

To create lift over hills or ridges, wind direction should be within about 30 to 40 degrees normal to the ridge line. A sustained speed of 15 knots or more usually generates enough lift to support a sailplane. Height of the lift usually is two or three times the height of the rise from the valley floor to the ridge crest. Strong winds tend to increase turbulence and low-level eddies without an appreciable increase in the height of the lift.

STABILITY

Stability affects the continuity and extent of lift over hills or ridges. Stable air allows relatively streamlined upslope flow. A pilot experiences little or no turbulence in the steady, uniform area of best lift shown in figure 168. Since stable air tends to return to its original level, air spilling over the crest and downslope is churned into a snarl of leeside eddies, also shown in figure 168. Thus, stable air favors smooth lift but troublesome leeside low-altitude turbulence.

When the airstream is moist and unstable, upslope lift may release the instability generating strong convective currents and cumulus clouds over windward slopes and hill crests. The initially laminar flow is broken up into convective cells. While the updrafts produce good lift, strong downdrafts may compromise low altitude flight over rough terrain. As with thermals, the lift will be transitory rather than smooth and uniform.

STEEPNESS OF SLOPE

Very gentle slopes provide little or no lift. Most favorable for soaring is a smooth, moderate slope. An ideal slope is about 1 to 4 which with an upslope wind of 15 knots creates lift of about 6 feet

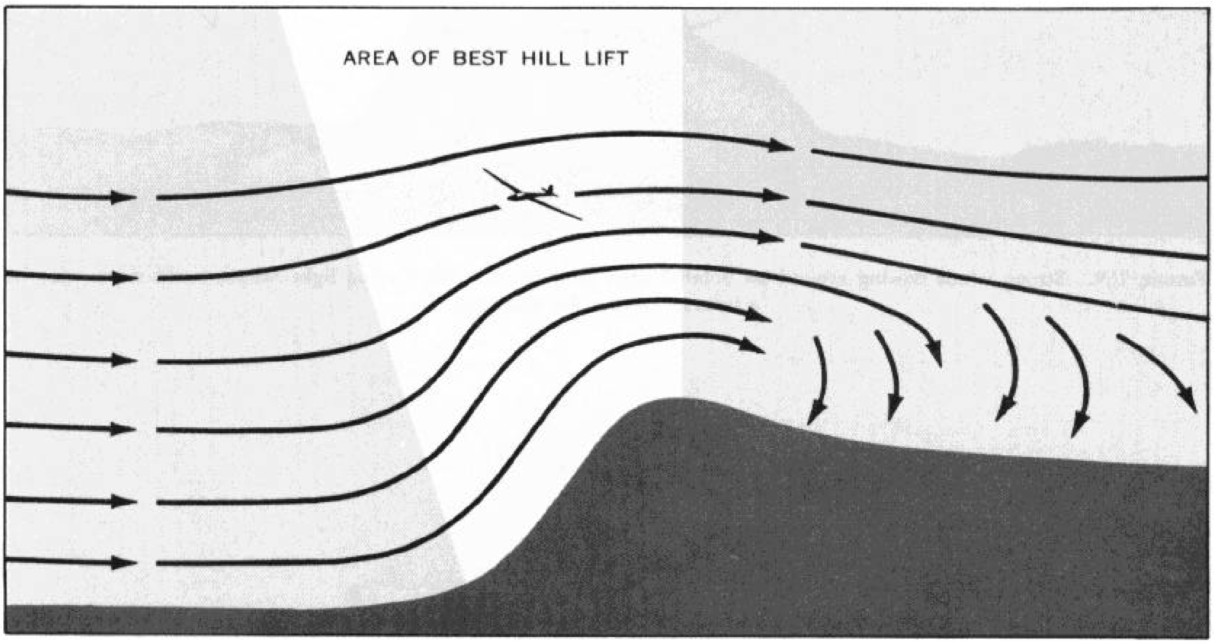

FIGURE 168. Schematic cross section of airflow over a ridge. Note the area of best lift. Downdrafts predominate leeward in the "wind shadow."

per second. With the same slope, a high-performance sailcraft with a sinking speed of 2 feet per second presumably could remain airborne with only a 5-knot wind!

Very steep escarpments or rugged slopes induce turbulent eddies. Strong winds extend these eddies to a considerable height usually disrupting any potential lift. The turbulent eddies also enhance the possibility of a low-altitude upset.

CONTINUITY OF RIDGES

Ridges extending for several miles without abrupt breaks tend to provide uniform lift through-

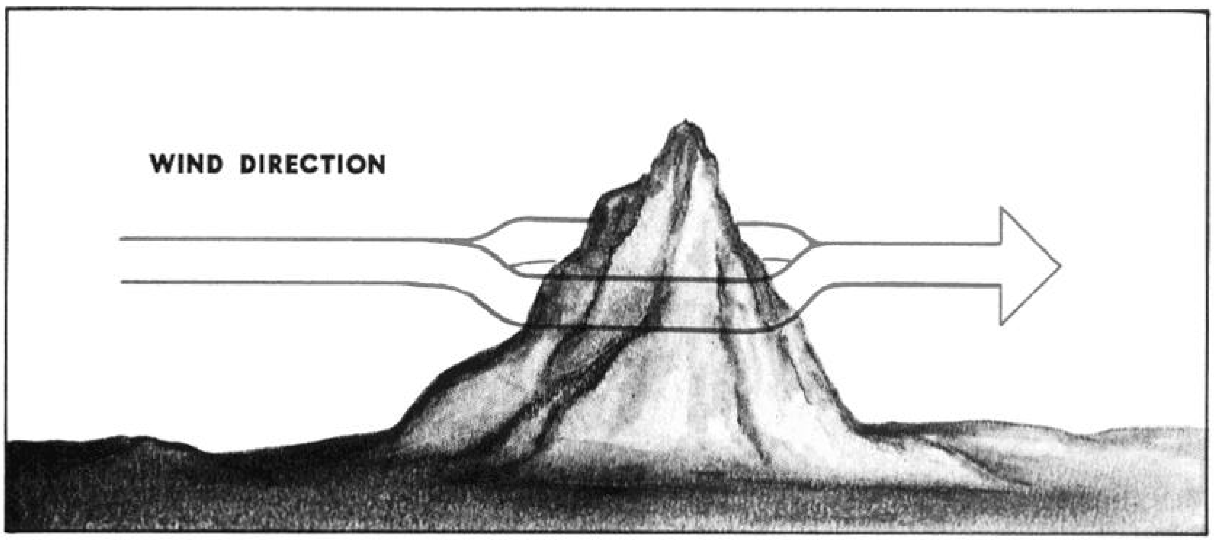

FIGURE 169. Strong winds flowing around an isolated peak produce little lift. During light winds, sunlit slopes may be a favored location for thermals.

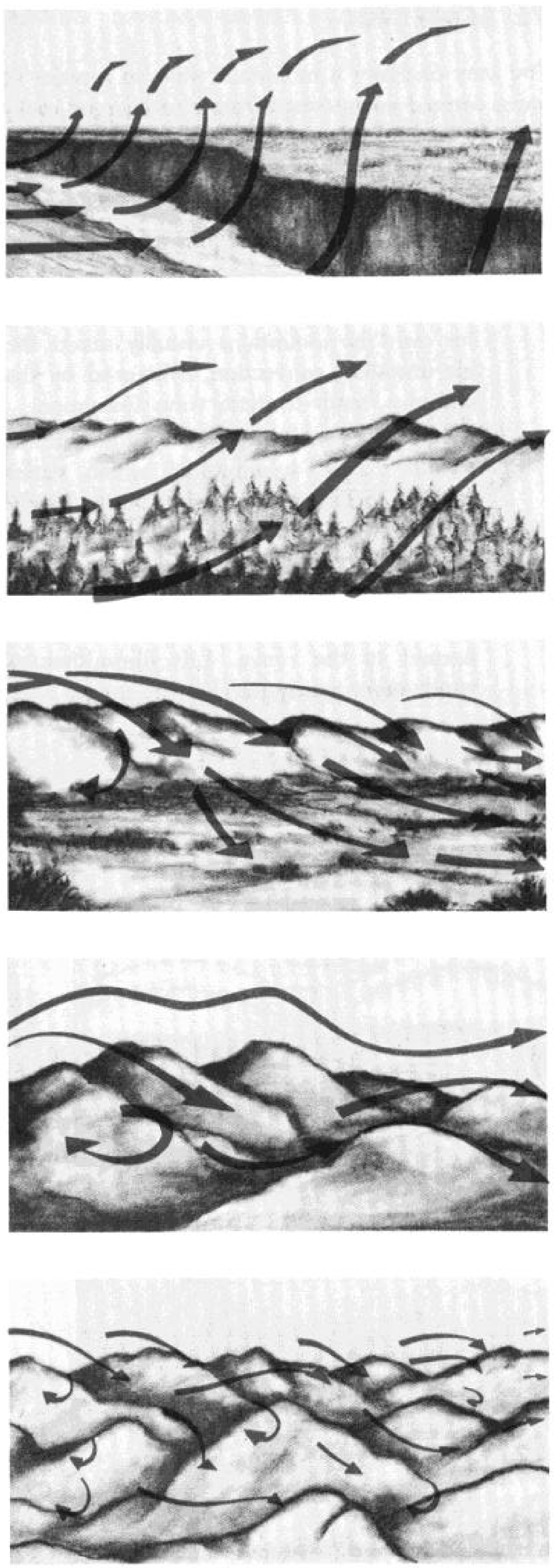

FIGURE 170. Windflow over various types of terrain. The many deviations from these patterns depend on wind speed, slope profile, and terrain roughness.

out their length. In contrast, a single peak diverts wind flow around the peak as well as over it and thus is less favorable for soaring. Figure 169 shows wind flow around an isolated peak.

Some wind flow patterns over ridges and hills are illustrated in figure 170. Deviations from these patterns depend on wind direction and speed, on stability, on slope profile, and on general terrain roughness.

SOARING IN UPSLOPE LIFT

The soaring pilot, always alert, must remain especially so in seeking or riding hill lift. You may be able to spot indicators of good lift. Other clues may mark areas to avoid.

When air is unstable, do not venture too near the slope. You can identify unstable air either by the updrafts and downdrafts in dry thermals or by cumulus building over hills or ridges. Approaching at too low an altitude may suddenly put you in a downdraft, forcing an inadvertent landing.

When winds are strong, surface friction may create low-level eddies even over relatively smooth slopes. Also, friction may drastically reduce the effective wind speed near the surface. When climbing at low altitude toward a slope under these conditions, be prepared to turn quickly toward the valley in event you lose lift. Renew your attempt to climb farther from the hill.

If winds are weak, you may find lift only very near the sloping surface. Then you must "hug" the slope to find needed lift. However, avoid this procedure if there are indications of up and down drafts. In general, for any given slope, keep your distance from the slope proportional to wind speed.

Leeward of hills and ridges is an area where wind is blocked by the obstruction. Among soaring circles this area is called the "wind shadow." In the wind shadow, downdrafts predominate as shown in figure 168. If you stray into the wind shadow at an altitude near or below the altitude of the ridge crest, you may be embarrassed by an unscheduled and possibly rough landing. Try to stay within the area of best lift shown in figure 168.

MOUNTAIN WAVE SOARING

The great attraction of soaring in mountain waves stems from the continuous lift to great heights. Soaring flights to above 35,000 feet have frequently been made in mountain waves. Once a soaring pilot has reached the rising air of a mountain wave, he has every prospect of maintaining flight for several hours. While mountain wave soaring is related to ridge or hill soaring, the lift in a mountain wave is on a larger scale and is less transitory than lift over smaller rises in terrain. Figure 171 is a cross section of a typical mountain wave.

FORMATION

When strong winds blow across a mountain range, large "standing" waves occur downwind from the mountains and upward to the tropopause. The waves may develop singly; but more often, they occur as a series of waves downstream from the mountains. While the waves remain about stationary, strong winds are blowing through them.

You may compare a mountain wave to a series of waves formed downstream from a submerged rocky ridge in a fast flowing creek or river. Air dips sharply immediately to the lee of a ridge, then rises and falls in a wave motion downstream.

A strong mountain wave requires:

1. Marked stability in the airstream disturbed by the mountains. Rapidly building cumulus over the mountains visually marks the air unstable; convection, evidenced by the cumulus, tends to deter wave formation.

2. Wind speed at the level of the summit should exceed a minimum which varies from 15 to 25 knots depending on the height of the range. Upper winds should increase or at least remain constant with height up to the tropopause.
3. Wind direction should be within 30 degrees normal to the range. Lift diminishes as winds more nearly parallel the range.

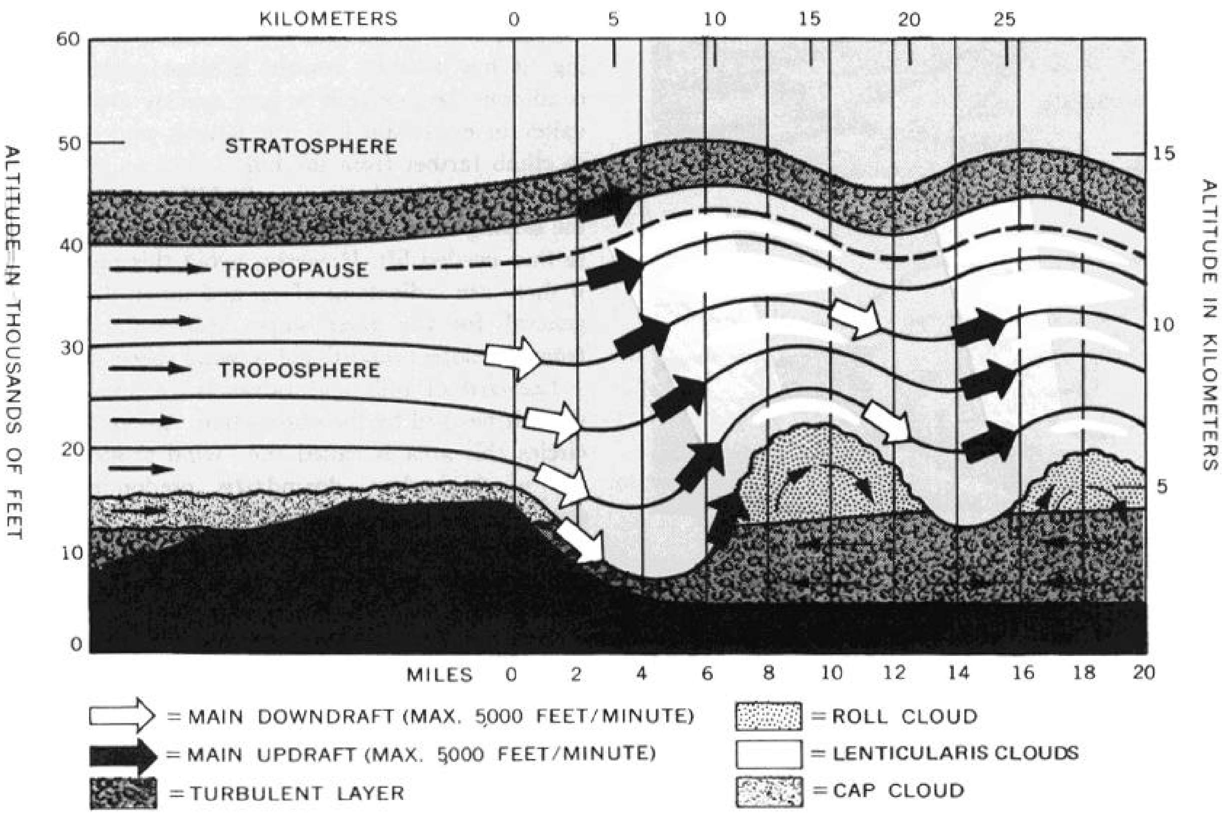

FIGURE 171. Schematic cross section of a mountain wave. Best lift is upwind from each wave crest for about one-third the distance to the preceding wave crest.

WAVE LENGTH AND AMPLITUDE

Wave length is the horizontal distance between crests of successive waves and is usually between 2 and 25 miles. In general, wave length is controlled by wind component perpendicular to the ridge and by stability of the upstream flow. Wave length is directly proportional to wind speed and inversely proportional to stability. Figure 172 illustrates wave length and also amplitude.

Amplitude of a wave is the vertical dimension and is half the altitude difference between the wave trough and crest. In a typical wave, amplitude varies with height above the ground. It is least near the surface and near the tropopause. Greatest amplitude is roughly 3,000 to 6,000 feet above the ridge crest. Wave amplitude is controlled by size and shape of the ridge as well as wind and stability. A shallow layer of great stability and moderate wind produces a greater wave amplitude than does a deep layer of moderate stability and strong winds. Also, the greater the amplitude, the shorter is the wave length. Waves offering the strongest and most consistent lift are those with great amplitude and short wave length.

VISUAL INDICATORS

If the air has sufficient moisture, lenticular (lens shaped) clouds mark wave crests. Cooling of air ascending toward the wave crest saturates the air forming clouds. Warming of air descending beyond the wave crest evaporates the cloud. Thus, by continuous condensation windward of the wave crest and evaporation leeward, the cloud appears stationary although wind may be blowing through the wave at 50 knots or more. Lenticular clouds in successive bands downstream from the mountain mark a series of wave crests.

Spacing of lenticulars marks the wave length. Clearly identifiable lenticulars also suggest larger wave amplitude than clouds which barely exhibit lenticular form. These cloud types along with stratiform clouds on the windward slopes and along the mountain crest indicate the stability favorable to mountain wave soaring.

Thunderstorms or rapidly building cumulus over mountains mark the air unstable. As they reach maturity, the thunderstorms often drift downwind across leeward valleys and plains. Strong convective currents in the unstable air deter wave formation. If you sight numerous instability clouds, wait until another day for mountain wave soaring.

SOARING TURBULENCE

A mountain wave, in a manner similar to that in a thermal, means turbulence to powered aircraft, but to a slowly moving sailcraft, it produces lift

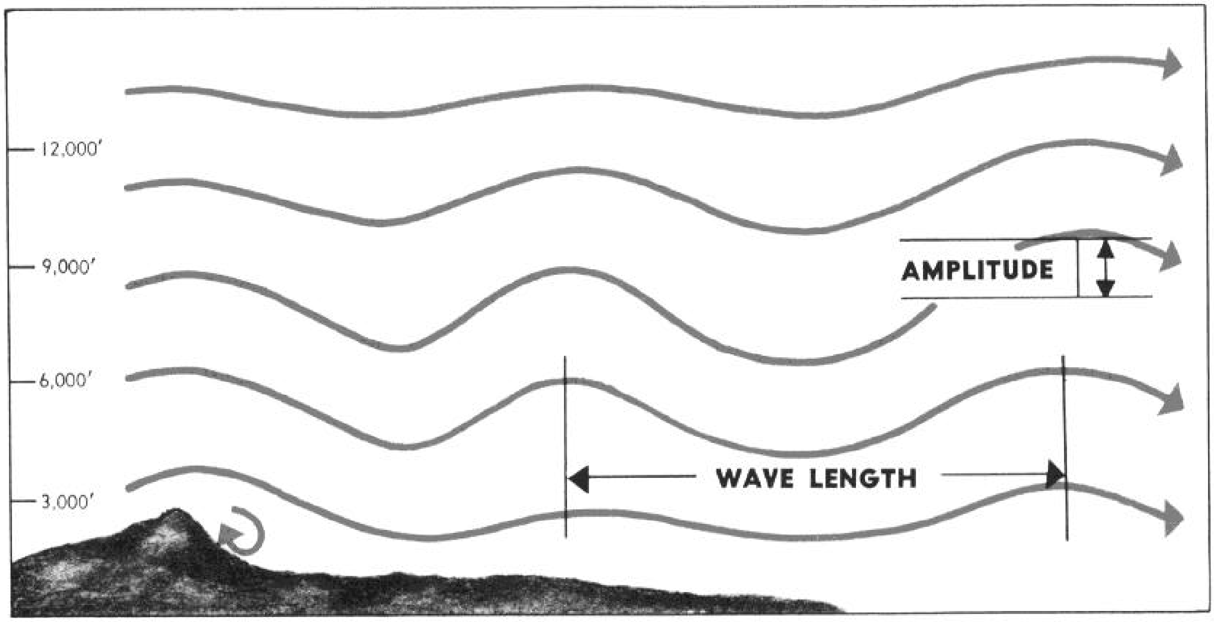

FIGURE 172. Wave length and amplitude.

and sink above the level of the mountain crest. But as air spills over the crest like a waterfall, it causes strong downdrafts. The violent overturning forms a series of "rotors" in the wind shadow of the mountain which are hazardous even to a sailplane (see ch. 9, figs. 81 through 84). Clouds resembling long bands of stratocumulus sometimes mark the area of overturning air. These "rotor clouds" appear to remain stationary, parallel the range, and stand a few miles leeward of the mountains. Turbulence is most frequent and most severe in the standing rotors just beneath the wave crests at or below mountain-top levels. This rotor turbulence is especially violent in waves generated by large mountains such as the Rockies. Rotor turbulence with lesser mountains is much less severe but is always present to some extent. The turbulence is greatest in well-developed waves.

FAVORED AREAS

Mountain waves occur most frequently along the central and northern Rockies and the northern Appalachians. Occasionally, waves form to the lee of mountains in Arkansas, Oklahoma, and southwestern Texas. Weather satellites have observed waves extending great distances downwind from the Rocky Mountains; one series extended for nearly 700 miles. The more usual distance is 150 to 300 miles. While Appalachian waves are not as strong as those over the Rockies, they occur frequently; and satellites have observed them at an average of 115 miles downwind. Wave length of these waves averages about 10 nautical miles.

RIDING THE WAVES

You often can detect a wave by the uncanny smoothness of your climb. On first locating a wave, turn into the wind and attempt to climb directly over the spot where you first detected lift *provided* you can remain at an altitude above the level of the mountain crest. ***The lee side turbulent area is for the experienced pilot only.*** After cautiously climbing well up into the wave, attempt to determine dimensions of the zone of lift. If the wave is over rugged terrain, it may be impossible and unnecessary to determine the wave length. Lift over such terrain is likely to be in patchy bands. Over more even terrain, the wave length may be easy to determine and use in planning the next stage of flight.

Wave clouds are a visual clue in your search for lift. The wave-like shape of lenticulars is usually more obvious from above than from below. Lift should prevail from the crest of the lenticulars upwind about one-third the wave length. When your course takes you across the waves, climb on the windward side of the wave and fly as quickly as possible to the windward side of the next wave. Wave lift of 300 to 1,200 feet per minute is not uncommon. Soaring pilots have encountered vertical currents exceeding 3,000 feet per minute, the strongest ever reported being 8,000 feet per minute.

IN CLOSING

Records are made to be broken. Altitude and distance records are a prime target of many sailplane enthusiasts. Distance records may be possible by flying a combination of lift sources such as thermal, frontal, ridge, or wave. Altitude records are set in mountain waves. Altitudes above 46,000 feet have been attained over the Rocky Mountains; soaring flights to more than 24,000 feet have been made in Appalachian waves; and flights to as high as 20,000 feet have been recorded from New England to North Carolina.

We sincerely hope that this chapter has given you an insight into the minute variations in weather that profoundly affect a soaring aircraft. When you have remained airborne for hours without power, you have met a unique challenge and experienced a singular thrill of flying.

GLOSSARY OF WEATHER TERMS

A

absolute instability—A state of a layer within the atmosphere in which the vertical distribution of temperature is such that an air parcel, if given an upward or downward push, will move away from its initial level without further outside force being applied.

absolute temperature scale—*See* Kelvin Temperature Scale.

absolute vorticity—*See* vorticity.

adiabatic process—The process by which fixed relationships are maintained during change in temperature, volume, and pressure in a body of air without heat being added or removed from the body.

advection—The horizontal transport of air or atmospheric properties. In meteorology, sometime referred to as the horizontal component of *convection*.

advection fog—Fog resulting from the transport of warm, humid air over a cold surface.

air density—The mass density of the air in terms of weight per unit volume.

air mass—In meteorology, an extensive body of air within which the conditions of temperature and moisture in a horizontal plane are essentially uniform.

air mass classification—A system wed to identify and to characterize the different *air masses* according to a basic scheme. The system most commonly used classifies air masses primarily according to the thermal properties of their *source regions:* "tropical" (T); "polar" (P); and "Arctic" or "Antarctic" (A). They are further classified according to moisture characteristics as "continental" (c) or "maritime" (m). air parcel—*See* parcel.

albedo—The ratio of the amount of electromagnetic *radiation* reflected by a body to the amount incident upon it, commonly expressed in percentage; in meteorology, usually wed in reference to *insolation* (solar radiation); i.e., the albedo of wet sand is 9, meaning that about 9% of the incident insolation is reflected; albedoes of other surface range upward to 80-85 for fresh snow cover; average albedo for the earth and its atmosphere has been calculated to range from 35 to 43.

altimeter—An instrument which determines the altitude of an object with respect to a fixed level. *See* pressure altimeter.

altimeter setting—The value to which the scale of a *pressure altimeter* is set so as to read true altitude at field elevation.

altimeter setting indicator—A precision *aneroid barometer* calibrated to indicate directly the altimeter setting.

altitude—Height expressed in units of distance above a reference plane, usually above mean sea level or above ground.

(I) corrected altitude—Indicated altitude of an aircraft altimeter corrected for the temperature of the column of air below the aircraft, the correction being based on the estimated departure of existing temperature from standard atmospheric temperature; an approximation of true altitude.

(2) density altitude—The altitude in the standard atmosphere at which the air has the same density as the air at the point in question. An aircraft will have the same performance characteristics as it would have in a standard atmosphere at this altitude.

(3) indicated altitude—The altitude above mean sea level indicated on a *pressure altimeter* set at current local *altimeter setting.*

(4) pressure altitude—The altitude in the standard atmosphere at which the pressure is the same as at the point in question. Since an altimeter operates solely on pressure, this ill the uncorrected altitude indicated by an altimeter set at standard sea level pressure of 29.92 inches or 1013 millibars.

(S) radar altitude—The altitude of an aircraft determined by radar-type radio altimeter; thus the actual distance from the nearest terrain or water feature encompassed by the downward directed radar beam. For all practical purpose, it ill the "actual" distance above a ground or inland water surface or the true altitude above an ocean surface.

(6) true altitude—The exact distance above mean sea level.

altocumulus–White or gray layers or patches of cloud, often with a waved appearance; cloud elements appear as rounded masses or rolls; composed mostly of liquid water droplets which may be supercooled; may contain ice crystals at subfreezing temperatures.

altocumulus castellanus–A species of middle cloud of which at least a fraction of its upper part presents some vertically developed, cumuliform protuberances (some of which are taller than they are wide, as castles) and which give the cloud a crenelated or turreted appearance; specially evident when seen from the side; elements usually have a common base arranged in lines. This cloud indicates instability and turbulence at the altitude of occurrence.

anemometer—An instrument for measuring *wind speed*.

aneroid barometer—A *barometer* which operates on the principle of having changing atmospheric pressure bend a metallic surface which, in turn, moves a pointer across a scale graduated in units of pressure.

angel—In radar meteorology, an *echo* caused by physical phenomena not discernible to the eye; they have been observed when abnormally strong temperature and/or moisture *gradients* were known to exist; sometime attributed to insects or birds flying in the radar beam.

anomalous propagation (sometimes called AP)—In radar meteorology, the greater than normal bending of the radar beam such that *echoes* are received from ground *targets* at distances greater than normal *ground clutter*.

anticyclone—An area of high atmospheric pressure which has a closed circulation that is anticyclonic, i.e., as viewed from above, the circulation is clockwise in the Northern Hemisphere, counterclockwise in the Southern Hemisphere, undefined at the Equator.

anvil cloud—Popular name given to the top portion of a *cumulonimbus* cloud having an anvil-like form.

APOB–A *sounding* made by an aircraft.

Arctic air—An air mass with characteristics developed mostly in winter over Arctic surfaces of ice and snow. Arctic air extends to great heights, and the surface temperatures are basically, but not always, lower than those *of polar* air.

Arctic front—The surface of discontinuity between very cold (Arctic) air flowing directly from the Arctic region and another less cold and, consequently, less dense air mass.

astronomical twilight—*See* twilight.

atmosphere—The mass of air surrounding the Earth.

atmospheric pressure (also called barometric pressure)— The pressure exerted by the atmosphere as a consequence of gravitational attraction exerted upon the "column" of air lying directly above the point in question.

atmospherics—Disturbing effects produced in radio receiving apparatus by atmospheric electrical phenomena such as an electrical storm. Static.

aurora—A luminous, radiant emission over middle and high latitudes confined to the thin air of high altitude and centered over the earth's magnetic pole. Called "aurora borealis" (northern lights) or "aurora borealis" according to its occurrence in the Northern or Southern Hemisphere, respectively.

attenuation—In radar meteorology, any process which reduces power density in radar signals.

(1) precipitation attenuation—Reduction of power density because of absorption or reflection of energy by precipitation.

(2) range attenuation—Reduction of radar power density because of distance from the antenna. It occurs in the outgoing beam at a rate proportional to l/range^2. The return signal is also attenuated at the same rate.

B

backing—Shifting of the wind in a counterclockwise direction with respect to either space or time; opposite of *veering.* Commonly used by meteorologists to refer to a cyclonic shift (counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere).

backscatter—Pertaining to radar, the energy reflected or scattered by a *target;* an *echo*.

banner cloud (al o called cloud banner)—A banner-like cloud streaming off from a mountain peak. barograph—A continuous-recording *barometer.*

barometer—An instrument for measuring the pressure of the atmosphere; the two principle type are *mercurial* and *aneroid*

barometric altimeter –*See* pressure altimeter. barometric pressure—Same as *atmospheric pressure.*

barometric tendency—The change of barometric pressure within a specified period of time. In aviation weather observations, routinely determined periodically, usually for a 3-hour period.

beam resolution–*See* resolution.

Beaufort Scale—A scale of wind speeds.

black blizzard–Same as *duststorm*

blizzard—A severe weather condition characterized by low temperatures and strong winds bearing a great amount of snow, either falling or picked up from the ground.

blowing dust—A type of *lithometeor* composed of dust particles picked up locally from the surface and blown about in clouds or sheets.

blowing and—A type of *lithometeor* composed of sand picked up locally from the surface and blown about in clouds or sheets.

blowing snow—A type of *hydrometeor* composed of snow picked up from the surface by the wind and carried to a height of 6 feet or more.

blowing spray—A type of *hydrometeor* composed of water particles picked up by the wind from the surface of a large body of water.

bright band—In radar meteorology, a narrow, intense *echo* on the *range-height indicator* scope resulting from watercovered ice particles of high reflectivity at the melting level.

Buys Ballot's Iaw—If an observer in the Northern Hemisphere stands with his back to the wind, lower pressure is to his left.

C

calm—The absence of wind or of apparent motion of the air.

cap cloud (al o called cloud cap)—A standing or stationary caplike cloud crowning a mountain summit.

ceiling—In meteorology in the U.S., (I) the height above the surface of the base of the lowest layer of clouds or *obscuring phenomena* aloft that hides more than half of the sky, or (2) the *vertical visibility* unto an *obscuration*. *See* summation principle.

ceiling balloon—A small balloon used to determine the height of a cloud base or the extent of vertical visibility.

ceiling light—An instrument which projects a vertical light beam onto the base of a cloud or into surface-based obscuring phenomena; used at night in conjunction with a *clinometer* to determine the height of the cloud base or as an aid in estimating the vertical visibility.

ceilometer—A cloud-height measuring system. It projects light on the cloud, detects the reflection by a photoelectric cell, and determines height by triangulation.

Celsius temperature scale (abbreviated C)—A temperature scale with zero degrees as the melting point of pure ice and 100 degrees as the boiling point of pure water at standard sea level atmospheric pressure.

Centigrade temperature scale—Same as *Celsius temperature scale.*

chaff—Pertaining to radar, (I) short, fine strips of metallic foil dropped from aircraft, usually by military forces, specifically for the purpose of jamming radar; (2) applied loosely to *echoes* resulting from chaff.

change of state—In meteorology, the transformation of water from one form, i.e., solid (ice), liquid, or gaseous (water vapor), to any other form. There are six possible transformations designated by the five terms following:

(I) **condensation—**The change of water vapor to liquid water.

(2) **evaporation—**The change of liquid water to water vapor.

(3) **freezing—**The change of liquid water to ice.

(4) **melting**—The change of ice to liquid water.

(5) **sublimation**—The change of (a) ice to water vapor or (b) water vapor to ice. *See* latent heat.

Chinook—A warm, *dry foehn* wind blowing down the eastern slopes of the Rocky Mountains over the adjacent plains in the U.S. and Canada.

cirriform—All species and varieties of *cirrus, cirrocumulus,* and *cirrostratus* clouds; descriptive of clouds composed mostly or entirely of small ice crystals, usually transparent and white; often producing *halo* phenomena not observed with other cloud forms. Average height ranges upward from 20,000 feet in middle latitudes.

cirrocumulus—A *cirriform* cloud appearing as a thin sheet of small white puffs resembling flakes or patches of cotton without shadows; sometimes confused with *altocumulus.*

cirrostratus—A *cirriform* cloud appearing as a whitish veil, usually fibrous, sometimes smooth; often produces *halo* phenomena; may totally cover the sky.

cirrus—A *cirriform* cloud in the form of thin, white featherlike clouds in patches or narrow bands; have a fibrous and/or silky sheen; large ice crystals often trail down ward a considerable vertical distance in fibrous, slanted, or irregularly curved wisps called mares' tails.

civil twilight—See twilight.

clear air turbulence (abbreviated CAT)—Turbulence encountered in air where no clouds are present; more popularly applied to high level turbulence associated with wind *shear.*

clear icing (or clear ice)–Generally, the formation of a layer or mass of ice which is relatively transparent because of its homogeneous structure and small number and size of air spaces; used commonly as synonymous with *glaze,* particularly with respect to aircraft icing. Compare with *rime* icing. Factors which favor clear icing are large drop size, such as those found in *cumuliform* clouds, rapid accretion of supercooled water, and slow dissipation of *latent heat* of fusion.

climate—The statistical collective of the weather conditions of a point or area during a specified interval of time' (usually several decades); may be expressed in a variety of ways.

climatology—The study of *climate.*

clinometer—An instrument used in weather observing for measuring angles of inclination; it is used in conjunction with a *ceiling light* to determine cloud height at night.

cloud bank—Generally, a fairly well-defined mass of cloud observed at a distance; it covers an appreciable portion of the horizon sky, but does not extend overhead.

cloudburst—In popular terminology, any sudden and heavy fall of *rain,* almost always of the *shower* type. **cloud cap**—*See* cap cloud.

cloud detection radar—A vertically directed radar to detect cloud bases and tops.

cold front—Any non-occluded front which moves in such a way that colder air replaces warmer air.

condensation—*See* change of state.

condensation level—The height at which a rising *parccl* or layer of air would become saturated if lifted adiabatically.

condensation nuclei—Small particles in the air on which water vapor condenses or sublimates.

condensation trail (or contrail) (also called vapor trail)— A cloud-like streamer frequently observed to form behind aircraft flying in clear, cold, humid air.

conditionally unstable air—Unsaturated air that will become unstable on the condition it becomes saturated. *See* instability.

conduction—The transfer of heat by molecular action through a substance or from one substance in contact with another; transfer is always from warmer to colder temperature.

constant pressure chart—A chart of a constant pressure surface; may contain analyses of height, wind, temperature, humidity, and/or other elements.

continental polar air—*See* polar air.

continental tropical air—*See* tropical air.

contour—In meteorology, (I) a line of equal height on a constant pressure chart; analogous to contours on a relief map; (2) in radar meteorology, a line on a radar scope of equal *echo* intensity.

contouring circuit–On weather radar, a circuit which displays multiple contours of *echo* intensity simultaneously on the *plan position indicator* or *range-height indicator* scope. *See* contour (2).

contrail—Contraction for *condensation trail*.

convection—(I) In general, mass motions within a fluid resulting in transport and mixing of the properties of that fluid. (2) In meteorology, atmospheric motions that are predominantly vertical, resulting in vertical transport and mixing of atmospheric properties; distinguished from *advection*.

convective cloud—*See* cumuliform.

convective condensation level (abbreviated CCL)— The lowest level at which condensation will occur as a result of *convection* due to surface heating. When condensation occurs at this level, the layer between the surface and the CC will be thoroughly mixed, temperature *lapse rate* will be dry adiabatic, and *mixing ratio* will be constant.

convective instability —The state of an unsaturated layer of air whose *lapse rates* of temperature and moisture are such that when lifted adiabatically until the layer becomes saturated, convection is spontaneous.

convergence—The condition that exists when the distribution of winds within a given area is such that there is a net horizontal inflow of air into the area. In convergence at lower levels, the removal of the resulting excess is accomplished by an upward movement of air; consequently, areas of low-level convergent winds are regions favorable to the occurrence of clouds and precipitation. Compare with *divergence*.

Coriolis force—A deflective force resulting from earth's rotation; it acts to the right of wind direction in the Northern Hemisphere and to the left in the Southern Hemisphere.

corona—A prismatically colored circle or arcs of a circle with the sun or moon at its center; coloration is from blue inside to red outside (opposite that of a *halo);* varies in size (much smaller) as opposed to the fixed diameter of the halo; characteristic of clouds composed of water droplets and valuable in differentiating between middle and cirriform clouds.

corposant—*See* St. Elmo's Fire.

corrected altitude (approximation of true altitude)— *See* altitude.

cumuliform—A term descriptive of all convective clouds exhibiting vertical development in contrast to the horizontally extended *stratiform* types.

cumulonimbus—A cumuliform cloud type; it is heavy and dense, with considerable vertical extent in the form of massive towers; often with tops in the shape of an *anvil* or massive plume; under the base of cumulonimbus, which often is very dark, there frequently exists *virga,* precipitation and low ragged clouds *(scud),* either merged with it or not; frequently accompanied by lightning, thunder, and sometimes hail; occasionally produces a tornado or a waterspout; the ultimate manifestation of the growth of a cumulus cloud, occasionally extending well unto the stratosphere.

cumulonimbus mamma—A *cumulonimbus* cloud having hanging protuberances, like pouches, festoons, or udders, on the under side of the cloud; usually indicative of severe turbulence.

cumulus– cloud in the form of individual detached domes or towers which are usually dense and well defined; develops vertically in the form of rising mounds of which the bulging upper part often resembles a cauliflower; the sunlit parts of these clouds are mostly brilliant white; their bases are relatively lark and nearly horizontal.

cumulus fractus–See fractus.

cyclogenesis–Any development or strengthening of cyclonic circulation in the atmosphere.

cyclone—(I) An area of low atmospheric pressure which has a closed circulation that is cyclonic, i.e., as viewed from above, the circulation is counterclockwise in the Northern Hemisphere, clockwise in the Southern Hemisphere, undefined at the Equator. Because cyclonic circulation and relatively low atmospheric pressure usually coexist, in common practice the terms cyclone and low are wed interchangeably. Also, because cyclones often are accompanied by inclement (sometimes destructive) weather, they are frequently referred to simply as storms. (2) Frequently misused to denote a *tornado. (3)* In the Indian Ocean, a *tropical cyclone* of hurricane or typhoon force.

D

deepening—A decrease in the central pressure of a pressure system; usually applied to a low rather than to a *high,* although technically, it is acceptable in either sense.

density—(I) The ratio of the mass of any substance to the volume it occupies—weight per unit volume. (2) The ratio of any quantity to the volume or area it occupies, i.e., population per unit area, *power density.*

density altitude—*See* altitude.

depression—In meteorology, an area of low pressure; a low or *trough.* This is usually applied to a certain stage in the development of a *tropical cyclone,* to migratory lows and troughs, and to upper-level lows and troughs that are only weakly developed.

dew—Water condensed onto grass and other objects near the ground, the temperatures of which have fallen below the initial dew point temperature of the surface air, but is still above freezing. Compare *with frost.*

dew point (or dew-point temperature)—The temperature to which a sample of air must be cooled, while the mixing ratio and barometric pressure remain constant, in order to attain saturation with respect to water.

discontinuity—A zone with comparatively rapid transition of one or more meteorological elements.

disturbance—In meteorology, applied rather loosely: (I) any low pressure or cyclone, but usually one that is relatively small in size; (2) an area where weather, wind, pressure, etc., show signs of cyclonic development; (3) any deviation in flow or pressure that is associated with a disturbed state of the weather, i.e., cloudiness and precipitation; and (4) any individual circulatory system within the primary circulation of the atmosphere.

diurnal—Daily, especially pertaining to a cycle completed within a 24-hour period, and which recurs every 24 hours.

divergence—The condition that exists when the distribution of winds within a given area is such that there is a net horizontal flow of air outward from the region. In divergence at lower levels, the resulting deficit is compensated for by subsidence of air from aloft; consequently the air is heated and the relative humidity lowered making divergence a warming and drying process. Low-level divergent regions are areas unfavorable to the occurrence of clouds and precipitation. The opposite of convergence.

doldrums–The equatorial belt of calm or light and variable winds between the two tradewind belts. Compare intatropical convergence zone.

downdraft—A relative small scale downward current of air; often observed on the lee side of large objects restricting the smooth flow of the air or in precipitation areas in or near cumuliform clouds.

drifting snow—A type of hydrometeor composed of snow particle picked up from the surface, but carried to a height of less than 6 feet.

drizzle—A form of precipitation. Very small water drops that appear to float with the air currents while falling in an irregular path (unlike rain, which falls in a comparatively straight path, and unlike fog droplets which remain suspended in the air).

dropsonde—A radiosonde dropped by parachute from an aircraft to obtain soundings (measurements) of the atmosphere below.

dry adiabatic lapse rate—The rate of decrease of temperature with height when unsaturated air is lifted adiabatically (due to expansion as it is lifted to lower pressure). *See* adiabatic process.

dry bulb—A name given to an ordinary thermometer wed to determine temperature of the air; also wed as a contraction for dry-bulb temperature. Compare wet bulb.

dry-bulb temperature—The temperature of the air.

dust—A type of lithometeor composed of small earthen particles suspended in the atmosphere.

dust devil—A small, vigorous whirlwind, usually of short duration, rendered visible by dust, sand, and debris picked up from the ground.

duster—Same as duststorm.

duststorm (also called duster, black blizzard)—An unusual, frequently severe weather condition characterized by strong winds and dust-filled air over an extensive area.

D-value—Departure of true altitude from pressure altitude *(see* altitude); obtained by algebraically subtracting true altitude from pressure altitude; thus it may be plus or minus. On a constant pressure chart, the difference between actual height and *standard atmospheric* height of a constant pressure surface.

E

echo—In radar, (I) the energy reflected or scattered by a *target; t2)* the radar scope presentation of the return from a target.

eddy—A local irregularity of wind in a larger scale wind flow. Small scale eddies produce turbulent conditions.

estimated ceiling—A ceiling classification applied when the ceiling height has been estimated by the observer or has been determined by some other method; but, because of the specified limits of time, distance, or precipitation conditions, a more descriptive classification cannot be applied.

evaporation—*See* change of state.

estratropical low (sometimes called estratropical cyclone, estratropical storm)—Any *cyclone* that is not a *tropical cyclone,* usually referring to the migratory frontal cyclones of middle and high latitudes.

eye—The roughly circular area of calm or relatively light winds and comparatively fair weather at the center of a well-developed *tropical cyclone.* A *wall cloud* marks the outer boundary of the eye.

F

Fahrenheit temperature scale (abbreviated F)—A temperature scale with *32* degrees as the melting point of pure ice and *212* degrees as the boiling point of pure water at standard sea level atmospheric pressure *(29.92* inches or *1013.2* millibars).

Fall wind—A cold wind blowing downslope. Fall wind differs *from foehn* in that the air is initially cold enough to remain relatively cold despite compressional heating during descent.

filling—An increase in the central pressure of a pressure system; opposite of *deepening;* more commonly applied to a low rather than a high.

first gust—The leading edge of the spreading downdraft, *plow wind,* from an approaching thunderstorm.

flow line—A *streamline.*

foehn—A warm, dry downslope wind; the warmness and dryness being due to adiabatic compression upon descent; characteristic of mountainous regions. *See* adiabatic process, Chinook, Santa Ana.

fog—A *hydrometeor* consisting of numerous minute water droplets and based at the surface; droplets are small enough to be suspended in the earth's atmosphere indefinitely. (Unlike *drizzle,* it does not fall to the surface; differs from cloud only in that a cloud is not based at the surface; distinguished from haze by its wetness and gray color.)

fractus–Clouds in the form of irregular shreds, appearing as if torn; have a clearly ragged appearance; applies only to stratus and cumulus, i.e., *cumulus* fractus and *stratus* fractus-.

freezing—See change of state.

freezing level—A level in the atmosphere at which the temperature is 0° C (32° F).

front—A surface, interface, or transition zone of discontinuity between two adjacent *air masses* of different densities; more simply the boundary between two different air masses. *See* frontal zone.

frontal zone—A *front* or zone with a marked increase of density gradient; wed to denote that fronts are not truly a "surface" of discontinuity but rather a "zone" of rapid transition of meteorological elements.

frontogenesis–The initial formation of a *front* or *frontal zone.*

frontolysis–The dissipation of *a front.*

frost (also hoarfrost)—Ice crystal deposits formed by sublimation when temperature and dew point are below freezing.

funnel cloud—A *tornado* cloud or *vortex* cloud extending downward from the parent cloud but not reaching the ground.

G

glaze—A coating of ice, generally clear and smooth, formed by freezing of supercooled water on a surface. *See* clear icing.

gradient—In meteorology, a horizontal decrease in value per unit distance of a parameter in the direction of maximum decrease; most commonly wed with pressure, temperature, and moisture.

ground clutter—Pertaining to radar, a cluster of *echoes,* generally at short range, reflected from ground *targets.*

ground fog—In the United States, *a fog* that conceals less than 0.6 of the sky and is not contiguous with the base of clouds.

gust—A sudden brief increase in wind; according to U.S. weather observing practice, gusts are reported when the variation in wind speed between peaks and lulls is at least 10 knots.

H

hail—A form of *precipitation* composed of balls or irregular lumps of ice, always produced by convective clouds which are nearly always *cumulonimbus.*

halo—A prismatically colored or whitish circle or arcs of a circle with the sun or moon at its center; coloration, if not white, is from red inside to blue outside (opposite that of a *corona);* fixed in size with an angular diameter of 22° (common) or 46° (rare); characteristic of clouds composed of ice crystals; valuable in differentiating between *cirriform* and forms of lower clouds.

haze—A type of *lithometeor* composed of fine dust or salt particles dispersed through a portion of the atmosphere; particle are so small they cannot be felt or individually seen with the naked eye (as compared with the larger particle of *dust),* but diminish the visibility; distinguished from fog by its bluish or yellowish tinge.

high—An area of high barometric pressure, with its attendant system of winds; an *anticyclone.* Also high pressure system.

hoar frost—*See* frost.

humidity—Water vapor content of the air; may be expressed as *specific humidity, relative humidity,* or mixing *ratio.*

hurricane—A *tropical cyclone* in the Western Hemisphere with winds in excess of 65 knots or 120 km/h.

hydrometeor—A general term for particle of liquid water or ice such as rain, fog, frost, etc., formed by modification of water vapor in the atmosphere; also water or ice particle lifted from the earth by the wind such as sea spray or blowing snow.

hygrograph—The record produced by a continuous recording *hygrometer.*

hygrometer—An instrument for measuring the water vapor content of the air.

I

ice crystals–A type of *precipitation* composed of unbranched crystals in the form of needles, columns, or plates; usually having a very slight downward motion, may fall from a cloudless sky.

ice fog—A type of fog composed of minute suspended particle of ice; occurs at very low temperatures and may cause *halo* phenomena.

ice needles—A form of *ice crystals.*

ice pellets—Small, transparent or translucent, round or irregularly shaped pellets of ice. They may be (I) hard grains that rebound on striking a hard surface or (2) pellets of snow encased in ice.

icing—In general, any deposit of ice forming on an object. *See* clear icing, rime icing, glaze.

indefinite ceiling—A ceiling classification denoting *vertical visibility* into a surface based obscuration.

indicated altitude—*See* altitude.

insolation—Incoming solar radiation falling upon the earth and its atmosphere.

instability—A general term to indicate various states of the atmosphere in which spontaneous convection will occur when prescribed criteria are met; indicative of turbulence. See absolute instability, conditionally unstable air, convective instability.

intertropical convergence zone—The boundary zone between the trade wind system of the Northern and Southern Hemispheres; it is characterized in maritime climate by showery precipitation with cumulonimbus clouds sometime extending to great heights.

inversion—An increase in temperature with height—a reversal of the normal decrease with height in the troposphere; may also be applied to other meteorological properties.

isobar—A line of equal or constant barometric pressure.

iso echo—In radar circuitry, a circuit that reverse signal strength above a specified intensity level, thus cawing a void on the scope in the most intense portion of an echo when maximum intensity is greater than the specified level.

isoheight–On a weather chart, a line of equal height; same as contour (1).

isoline—A line of equal value of a variable quantity, i.e., an isoline of temperature is an isotherm, etc. See isobar, isotach, etc.

isoshear—A line of equal wind shear.

isotach—A line of equal or constant wind speed. isotherm—A line of equal or constant temperature.

isothermal–Of equal or constant temperature, with respect to either space or time; more commonly, temperature with height; a zero lapse rate.

jet stream—A quasi-horizontal stream of winds 50 knots or more concentrated within a narrow band embedded in the westerlies in the high troposphere.

K

katabatic wind—Any wind blowing downslope. See fall wind, foehn.

Kelvin temperature scale (abbreviated K)—A temperature scale with zero degree equal to the temperature at which all molecular motion ceases, i.e., absolute zero (0° K = —273° C); the Kelvin degree is identical to the Celsius degree; hence at standard sea level pressure, the melting point is 273° K and the boiling point 373° K.

knot—A unit of speed equal to one nautical mile per hour.

L

land breeze—A coastal breeze blowing from land to sea, caused by temperature difference when the sea surface is warmer than the adjacent land. Therefore, it usually blows at night and alternates with a sea breeze, which blows in the opposite direction by day.

lapse rate—The rate of decrease of an atmospheric variable with height; commonly refers to decrease of temperature with height.

latent heat—The amount of heat absorbed (converted to kinetic energy) during the processes of change of liquid water to water vapor, ice to water vapor, or ice to liquid water; or the amount released during the reverse processes. Four basic classifications are:

(I) **latent heat of condensation**—Heat released during change of water vapor to water.

(2) **latent heat of fu ion**—Heat released during change of water to ice or the amount absorbed in change of ice to water.

(3) **latent heat of sublimation**—Heat released during change of water vapor to ice or the amount absorbed in the change of ice to water vapor.

(4) **latent heat of vaporization**—Heat absorbed in the change of water to water vapor; the negative of latent heat of condensation.

layer—In reference to sky cover, clouds or other obscuring phenomena whose bases are approximately at the same level. The layer may be continuous or composed of detached elements. The term "layer" does not imply that a clear space exists between the layers or that the clouds or obscuring phenomena composing them are of the same type.

lee wave—Any stationary wave disturbance caused by a barrier in a fluid flow. In the atmosphere when sufficient moisture is present, this wave will be evidenced by lenticular clouds to the lee of mountain barriers; also called mountain wave or standing wave.

lenticular cloud (or lenticularis)—A species of cloud whose elements have the form of more or less isolated, generally smooth lenses or almonds. These clouds appear most often in formations of orographic origin, the result of lee waves, in which case they remain nearly stationary with respect to the terrain (standing cloud), but they also occur in regions without marked orography.

level of free convection (abbreviated LFC)—The level at which a parccl of air lifted dry-adiabatically until saturated and moist-adiabatically thereafter would become warmer than its surroundings in a conditionally unstable atmosphere. See. conditional instability and adiabatic process.

lifting condensation level (abbreviated LCL)—The level at which a parccl of unsaturated air lifted dryadiabatically would become saturated. Compare level of free convection and convective condensation level.

lightning–Generally, any and all forms of visible electrical discharge produced by a thunderstorm.

lithometeor—The general term for dry particle suspended in the atmosphere such as dust, haze, smoke, and sand.

low—An area of low barometric pressure, with its attendant system of winds. Also called a barometric depression or cyclone.

M

mammato cumulus–Obsolete. See cumulonimbus mamma. mare's tail—See cirrus. maritime polar air (abbreviated mP)—See polar air. maritime tropical air (abbreviated mT)—See tropical air.

maximum wind axis–On a constant pressure chart, a line denoting the axis of maximum wind speeds at that constant pressure surface.

mean sea level—The average height of the surface of the sea for all stages of tide; wed as reference for elevations throughout the U.S.

measured ceiling—A ceiling classification applied when the ceiling value has been determined by instruments or the known heights of unobscured portions of objects, other than natural landmarks. melting—See change of state.

mercurial barometer—A *barometer* in which pressure is determined by balancing air pressure against the weight of a column of mercury in an evacuated glass tube.

meteorological visibility—In U.S. observing practice, a main category of visibility which include the subcategories of prevailing visibility and runway visibility. Meteorological visibility i8 a measure of horizontal visibility near the earth's surface, based on sighting of objects in the daytime or unfocused lights of moderate intensity at night. Compare slant visibility, runway visual range, vertical visibility. See surface visibility, tower visibility, and sector visibility.

meteorology—The science of the atmosphere.

microbarograph—An aneroid barograph designed to record atmospheric pressure changes of very small magnitudes.

millibar (abbreviated mb.)—An internationally wed unit of pressure equal to 1,000 dynes per square centimeter. It is convenient for reporting atmospheric pressure.

mist—A popular expression for drizzle or heavy fog.

mixing ratio—The ratio by weight of the amount of water vapor in a volume of air to the amount of dry air; usually expressed as grams per kilogram (g/kg).

moist adiabatic lapse rate—See saturated-adiabatic lapse rate.

moisture—An all-inclusive term denoting water in any or all of its three states.

monsoon—A wind that in summer blows from sea to a continental interior, bringing copious rain, and in winter blows from the interior to the sea, resulting in sustained dry weather.

mountain wave—A standing wave or ice wave to the lee of a mountain barrier.

N

nautical twilight—See twilight.

negative vorticity—See vorticity.

nimbostratus–A principal cloud type, gray colored, often dark, the appearance of which is rendered diffuse by more or less continuously falling rain or snow, which in most cases reaches the ground. It is thick enough throughout to blot out the sun.

noctilucent clouds–Clouds of unknown composition which occur at great heights, probably around 75 to 90 kilometers. They resemble thin cirrus, but usually with a bluish or silverish color, although sometimes orange to red, standing out against a dark night sky. Rarely observed.

normal—In meteorology, the value of an element averaged for a given location over a period of years and recognized as a standard.

numerical forecasting—See numerical weather prediction.

numerical weather prediction—Forecasting by digital computers solving mathematical equations; wed extensively in weather services throughout the world.

O

obscuration—Denotes sky hidden by surface-based obscuring phenomena and vertical visibility restricted overhead.

obscuring phenomena—Any hydrometeor or lithometeor other than clouds; may be surface based or aloft.

occlusion–Same as occluded front.

occluded front (commonly called occlusion, also called frontal occlusion)—A composite of two fronts as a cold front overtakes a warmfront or quasi-stationary front.

orographic–Of, pertaining to, or caused by mountains as in orographic clouds, orographic lift, or orographic precipitation.

ozone—An unstable form of oxygen; heaviest concentrations are in the stratosphere; corrosive to some metals; absorbs most ultraviolet solar radiation.

P

parcel—A small volume of air, small enough to contain uniform distribution of its meteorological properties, and large enough to remain relatively self-contained and respond to all meteorological processes. No specific dimensions have been defined, however, the order of magnitude of I cubic foot has been suggested.

partial obscuration—A designation of sky cover when part of the sky is hidden by surface based obscuring phenomena.

pilot balloon—A small free-lift balloon wed to determine the speed and direction of winds in the upper air.

pilot balloon observation (commonly called PIBAL)—A method of winds-aloft observation by visually tracking a pilot balloon.

plan position indicator (PPI) scope—A radar indicator scope displaying range and azimuth of targets in polar coordinates.

plow wind—The spreading downdraft of a thunderstorm; a strong, straight-line wind in advance of the storm. See first gust.

polar air—An air mass with characteristics developed over high latitude, especially within the subpolar highs. Continental polar air (cP) has cold surface temperature, low moisture content, and, especially in its source regions, has great stability in the lower layers. It is shallow in comparison with Arctic air. Maritime polar (mP) initially possesses similar properties to those of continental polar air, but in passing over warmer water-it becomes unstable with a higher moisture content. Compare tropical air.

polar front—The semipermanent, semicontinuous front separating air masses of tropical and polar origins.

positive vorticity—See vorticity.

power density—In radar meteorology the amount of radiated energy per unit cross sectional area in the radar beam.

precipitation—Any or all forms of water particle, whether liquid or solid, that fall from the atmosphere and reach the surface. It is a major class of hydrometeor, distinguished from cloud and virga in that it must reach the surface. precipitation attenuation—See attenuation. pressure—See atmospheric pressure.

pressure altimeter—An aneroid barometer with a scale graduated in altitude instead of pressure using standard atmospheric pressure-height relationships; shows indicated altitude (not necessarily true altitude); may be set to measure altitude (indicated) from any arbitrarily chosen level. See altimeter setdng, altitude. pressure altitude—See altitude.

pressure gradient—The rate of decrease of pressure per unit distance at a fixed time.

pressure jump—A sudden, significant increase in station pressure.

pressure tendency—See barometric tendency.

prevailing westerlies–The broad current or pattern of persistent easterly winds in the Tropics and in polar regions.

prevailing visibility—In the U.S., the greatest horizontal visibility which is equaled or exceeded throughout half of the horizon circle; it need not be a continuous half

prevailing westerlies—The dominant west-to-east motion of the atmosphere, centered over middle latitude of both hemispheres.

prevailing wind—Direction from which the wind blows most frequently.

prognostic chart (contracted PROG)—A chart of expected or forecast conditions.

pseudo-adiabatic lapse rate—See saturated-adiabatic lapse rate.

psychrometer—An instrument consisting of a wet-bulb and a dry-bulb thermometer for measuring wet-bulb and drybulb temperature; wed to determine water vapor content of the air.

pulse—Pertaining to radar, a brief burst of electromagnetic radiation emitted by the radar; of very short time duration. See pulse length.

pulse length—Pertaining to radar, the dimension of a radar pulse; may be expressed as the time duration or the length in linear units. Linear dimension is equal to time duration multiplied by the speed of propagation (approximately the speed of light).

Q

quasi-stationary front (commonly called stationary front)—A front which i8 stationary or nearly so; conventionally, a front which i8 moving at a speed of less than 5 knots i8 generally considered to be quasi-stationary.

R

RADAR (contraction for radio detection and ranging)— An electronic instrument used for the detection and ranging of distant objects of such composition that they scatter or reflect radio energy. since hydrometeors can scatter radio energy, weather radars, operating on certain frequency bands, can detect the presence of precipitation, clouds, or both.

radar altitude—See altitude.

radar beam—The focused energy radiated by radar similar to a flashlight or searchlight beam. radar echo—See echo.

radarsonde observation—A rawinsonde observation in which winds are determined by radar tracking a balloon-borne target.

radiation—The emission of energy by a medium and transferred, either through free space or another medium, in the form of electromagnetic wave.

radiation fog—Fog characteristically resulting when radiational cooling of the earth's surface lowers the air temperature near the ground to or below its initial dew point on calm, clear nights.

radiosonde—A balloon-borne instrument for measuring pressure, temperature, and humidity aloft.

radiosonde observation—a sounding made by the instrument.

rain—A form of precipitation; drops are larger than drizzle and fall in relatively straight, although not necessarily vertical, paths as compared to drizzle which falls in irregular paths.

rain shower—See shower.

range attenuation—See attenuation.

range-height indicator (RHI) scope—A radar indicator scope displaying a vertical cross section of targets along a selected azimuth.

range resolution—See resolution.

RAOB—A radiosonde observation.

rawin—A rawinsonde observation.

rawinsonde observation—A combined winds aloft and radiosonde observation. Winds are determined by tracking the radiosonde by radio direction finder or radar.

refraction—In radar, bending of the radar beam by variations in atmospheric density, water vapor content, and temperature.

(I) **normal refraction**—Refraction of the radar beam under normal atmospheric conditions; normal radius of curvature of the beam is about 4 times the radius of curvature of the Earth.

(2) **superrefraction**—More than normal bending of the radar beam resulting from abnormal vertical gradients of temperature and/or water vapor.

(3) **subrefraction**—Less than normal bending of the radar beam resulting from abnormal vertical gradients of temperature and/or water vapor.

relative humidity—The ratio of the existing amount of water vapor in the air at a given temperature to the maximum amount that could exist at that temperature; usually expressed in percent. relative vorticity—See vorticity.

remote scope—In radar meteorology a "slave" scope remoted from weather radar.

resolution—Pertaining to radar, the ability of radar to show discrete targets separately, i.e., the better the resolution, the closer two targets can be to each other, and still be detected as separate targets.

(I) **beam resolution**—The ability of radar to distinguish between targets at approximately the same range but at different azimuths.

(2) **range resolution**—The ability of radar to distinguish between targets on the same azimuth but at different ranges.

ridge (also called ridge line)—In meteorology, an elongated area of relatively high atmospheric pressure; usually associated with and most clearly identified as an area of maximum anticyclonic curvature of the wind flow (isobars, contours, or streamlines).

rime icing (or rime ice)—The formation of a white or milky and opaque granular deposit of ice formed by the rapid freezing of supercooled water droplets as they impinge upon an exposed aircraft.

rocketsonde—A type of radiosonde launched by a rocket and making its measurements during a parachute descent; capable of obtaining soundings to a much greater height than possible by balloon or aircraft.

roll cloud (sometimes improperly called rotor cloud)— A dense and horizontal roll-shaped accessory cloud located on the lower leading edge of a cumulonimbus or less often, a rapidly developing cumulus; indicative of turbulence.

rotor cloud (sometimes improperly called roll cloud)— A turbulent cloud formation found in the lee of some large mountain barriers, the air in the cloud rotates around an axis parallel to the range; indicative of possible violent turbulence.

runway temperature—The temperature of the air just above a runway, ideally at engine and/or wing height, wed in the determination of density altitude; useful at airports when critical values of density altitude prevail.

runway visibility—The meteorological visibility along an identified runway determined from a specified point on the runway; may be determined by a transmissometer or by an observer.

runway visual range—An instrumentally derived horizontal distance a pilot should see down the runway from the approach end; based on either the sighting of high intensity runway lights or on the visual contrast of other objects, whichever yields the greatest visual range.

S

St. Elmo's Fire (also called corposant)—A luminous brush discharge of electricity from protruding objects, such as masts and yardarms of ships, aircraft, lightning rods, steeples, etc., occurring in stormy weather.

Santa Ana—A hot, dry, foehn wind, generally from the northeast or east, occurring west of the sierra Nevada Mountains specially in the pass and river valley near Santa Ana, California.

saturated adiabatic lapse rate—The rate of decrease of temperature with height as saturated air is lifted with no gain or loss of heat from outside source; varies with temperature, being greatest at low temperature. See adiabatic process and dry-adiabatic lapse rate.

saturation—The condition of the atmosphere when actual water vapor present is the maximum possible at existing temperature.

scud—Small detached masses of stratus fractus clouds below a layer of higher clouds, usually nimbostratus.

sea breeze—A coastal breeze blowing from sea to land, caused by the temperature difference when the land surface i8 warmer than the sea surface. Compare land breeze.

sea fog—A type of advection fog formed when air that has been lying over a warm surface is transported over a colder water surface.

sea level pressure—The atmospheric pressure at mean sea level, either directly measured by stations at sea level or empirically determined from the station pressure and temperature by stations not at sea level; used as a common reference for analyses of surface pressure patterns.

sea smoke—Same as steam fog.

sector visibility—Mctcorological visibility within a specified sector of the horizon circle.

sensitivity time control—A radar circuit designed to correct for range attenuation so that echo intensity on the scope is proportional to reflectivity of the target regardless of range.

shear—See wind shear.

shower—Precipitation from a cumuliform cloud; characterized by the suddenness of beginning and ending, by the rapid change of intensity, and usually by rapid change in the appearance of the sky; showery precipitation may be in the form of rain, ice pellets, or snow.

slant visibility—For an airborne observer, the distance at which he can see and distinguish objects on the ground.

sleet—See ice pellets.

smog—A mixture of smoke and fog.

smoke—A restriction to visibility resulting from combustion.

snow—Precipitation composed of white or translucent ice crystals, chiefly in complex branched hexagonal form.

snow flurry—Popular term for snow shower, particularly of a very light and brief nature.

snow grains—Precipitation of very small, white opaque grains of ice, similar in structure to snow crystals. The grains are fairly flat or elongated, with diameters generally less than 0.04 inch (I mm.).

snow pellet–Precipitation consisting of white, opaque approximately round (sometimes conical) ice particles having a snow-like structure, and about 0.08 to 0.2 inch in diameter; crisp and easily crushed, differing in this respect from snow grains; rebound from a hard surface and often break up.

snow shower—See shower.

solar radiation—The total electromagnetic radiation emitted by the sun. See insolation.

sounding—In meteorology, an upper-air observation; a radiosonde observation.

source region—An extensive area of the earth's surface characterized by relatively uniform surface conditions where large masses of air remain long enough to take on characteristic temperature and moisture properties imparted by that surface.

specific humidity—The ratio by weight of water vapor in a sample of air to the combined weight of water vapor and dry air. Compare mixing ratio.

squall—A sudden increase in wind speed by at least 15 knots to a peak of 20 knots or more and lasting for at least one minute. Essential difference between a gust and a squall is the duration of the peak speed.

squall line—Any nonfrontal line or narrow band of active thunderstorms (with or without squalls).

stability—A state of the atmosphere in which the vertical distribution of temperature is such that a parcel will resist displacement from its initial level. (See also instability.)

standard atmosphere—A hypothetical atmosphere based on climatological average comprised of numerous physical constants of which the most important are:

(I) A surface temperature of 59° F (15° C) and a surface pressure of 29.92 inches of mercury (1013.2 millibars) at sea level;

(2) A lapse rate in the troposphere of 6.5° C per kilometer (approximately 2° C per 1,000 feet);

(3) A tropopause of 11 kilometers (approximately 36,000 feet) with a temperature of—56.5° C; and

(4) An isothermal lapse rate in the stratosphere to an altitude of 24 kilometers (approximately 80,000 feet).

standing cloud (standing lenticular altocumulus)—See lenticular cloud.

standing wave—A wave that remains stationary in a moving fluid. In aviation operations it is used most commonly to refer to a ice wave or mountain wave.

stationary front—Same as quasi-stationary front.

station pressure—The actual atmospheric pressure at the observing station.

steam fog—Fog formed when cold air moves over relatively warm water or wet ground.

storm detection radar—A weather radar designed to detect hydrometeors of precipitation size; used primarily to detect storms with large drops or hailstones as opposed to clouds and light precipitator. of small drop size.

stratiform—Descriptive of clouds of extensive horizontal development, as contrasted to vertically developed cumuliform clouds; characteristic of stable air and, therefore, composed of small water droplets.

stratocumulus—A low cloud, predominantly stratiform in gray and/or whitish patches or layers, may or may not merge; elements are tessellated, rounded, or roll-shaped with relatively flat tops.

stratosphere—The atmospheric layer above the tropopause, average altitude of base and top, 7 and 22 miles respectively; characterized by a slight average increase of temperature from base to top and is very stable; also characterized by low moisture content and absence of clouds.

stratus—A low, gray cloud layer or sheet with a fairly uniform base; sometimes appears in ragged patches; seldom produces precipitation but may produce drizzle or snow grains. A stratiform cloud.

stratus fractus—See fractus.

streamline—In meteorology, a line whose tangent is the wind direction at any point along the line. A flowline.

sublimation—See change of state.

subrefraction—See refraction.

subsidence—A descending motion of air in the atmosphere over a rather broad area; usually associated with divergence.

summation principle—The principle states that the cover assigned to a layer is equal to the summation of the sky cover of the lowest layer plus the additional coverage at all successively higher layers up to and including the layer in question. Thus, no layer can be assigned a sky cover less than a lower layer, and no sky cover can be greater than 1.0 (10/10).

superadiabatic lapse rate—A lapse rate greater than the dry-adiabatic lapse rate. See absolute instability.

supercooled water—Liquid water at temperatures colder than freezing. superrefraction—See refraction.

surface inversion—An invasion with its base at the surface, often cawed by cooling of the air near the surface as a result of terrestrial radiation, especially at night.

surface visibility—Visibility observed from eye-level above the ground.

synoptic chart—A chart, such as the familiar weather map, which depicts the distribution of meteorological conditions over an area at a given time.

T

target—In radar, any of the many types of objects detected by radar.

temperature—In general, the degree of hotness or coldness as measured on some definite temperature scale by means of any of various types of thermometers. temperature inversion—See inversion.

terrestrial radiation—The total infrared radiation emitted by the Earth and its atmosphere.

thermograph—A continuous-recording thermometer.

thermometer—An instrument for measuring temperature.

theodolite—An optical instrument which, in meteorology, i8 used principally to observe the motion of a pilot balloon.

thunderstorm—In general, a local storm invariably produced by a cumulonimbus cloud, and always accompanied by lightning and thunder.

tornado (sometimes called cyclone, twister)—A violently rotating column of air, pendant from a cumulonimbus cloud, and nearly always observable as "funnel-shaped." It is the most destructive of all small-scale atmospheric phenomena.

towering cumulus–A rapidly growing cumulus in which height exceeds width.

tower visibility—Prevailing visibility determined from the control tower.

trade wind–Prevailing, almost continuos winds blowing with an easterly component from the subtropical high pressure belts toward the intatropical convergence zone; northeast in the Northern Hemisphere, southeast in the Southern Hemisphere.

transmissometer—An instrument system which shows the transmissivity of light through the atmosphere. Transmissivity may be translated either automatically or manually into visibility and/or runway visual range.

tropical air—An air mass with characteristics developed over low latitude. Maritime tropical air (mT), the principal type, is produced over the tropical and subtropical seas; very warm and humid. Continental tropical (cT) is produced over subtropical arid regions and is hot and very dry. Compare polar air.

tropical cyclone—A general term for a cyclone that originates over tropical oceans. By international agreement, tropical cyclones have been classified according to their intensity, as follows:

(I) **tropical depression**—winds up to 34 knots (64 lcm/h);

(2) **tropical storm**—winds of 35 to 64 knots (65 to 119 km/h);

(3) **hurricane or typhoon**—winds of 65 knots or higher (120 km/h). tropical depression—See tropical cyclone.

tropical storm—See tropical cyclone.

tropopause—The transition zone between the troposphere and stratosphere, usually characterized by an abrupt change of lapse rate.

troposphere—That portion of the atmosphere from the earth's surface to the tropopause; that is, the lowest 10 to 20 kilometers of the atmosphere. The troposphere is characterized by decreasing temperature with height, and by appreciable water vapor.

trough (also called trough line)—In meteorology, an elongated area of relatively low atmospheric pressure; usually associated with and most clearly identified as an area of maximum cyclonic curvature of the wind flow (isobars, contours, or streamlines); compare with ridge.

true altitude—See altitude.

true wind direction—The direction, with respect to true north, from which the wind is blowing.

turbulence—In meteorology, any irregular or disturbed flow in the atmosphere.

twilight—The intervals of incomplete darkness following sunset and preceding sunrise. The time at which evening twilight ends or morning twilight begins is determined by arbitrary convention, and several kinds of twilight have been defined and wed; most commonly civil, nautical, and astronomical twilight.

(I) **Civil Twilight**—The period of time before sunrise and after sunset when the sun is not more than 6° below the horizon.

(2) **Nautical Twilight**—The period of time before sunrise and after sunset when the sun i8 not more than 12° below the horizon.

(3) **Astronomical Twilight**—The period of time before sunrise and after sunset when the sun is not more than 18° below the horizon. twister—In the United States, a colloquial term for tornado.

typhoon—A tropical cyclone in the Eastern Hemisphere with winds in excess of 65 knots (120 km/h).

U

undercast—A cloud layer of ten-tenths (1.0) coverage (to the nearest tenth) as viewed from an observation point above the layer.

unlimited ceiling—A clear sky or a sky cover that does not meet the criteria for a ceiling.

unstable—See instability.

updraft—A localized upward current of air.

upper front—A front aloft not extending to the earth's surface.

upslope fog—Fog formed when air flows upward over rising terrain and is, consequently, adiabatically cooled to or below its initial dew point.

V

vapor pressure—In meteorology, the pressure of water vapor in the atmosphere. Vapor pressure is that part of the total atmospheric pressure due to water vapor and is independent of the other atmospheric gases or vapors.

vapor trail—Same as condensation trail.

veering—Shifting of the wind in a clockwise direction with respect to either space or time; opposite of backing. Commonly used by meteorologists to refer to an and cyclonic shift (clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere).

vertical visibility—The distance one can see upward into a surface based obscuration; or the maximum height from which a pilot in flight can recognize the ground through a surface based obscuration.

virga—Water or ice particles falling from a cloud, usually in wisps or streaks, and evaporating before reaching the ground.

visibility—The greatest distance one can see and identify prominent objects. visual range—See runway visual range.

vortex—In meteorology, any rotary flow in the atmosphere.

vorticity—Turning of the atmosphere. Vorticity may be imbedded in the total flow and not readily identified by a flow pattern.

(a) **absolute vorticity**—the rotation of the Earth imparts vorticity to the atmosphere; absolute vorticity is the combined vorticity due to the rotation and vorticity due to circulation relative to the Earth (relative vorticity).

(b) **negative vorticity**—vorticity cawed by anticyclonic turning; it is associated with downward motion of the air.

(c) **positive vorticity**—vorticity cawed by cyclonic turning; it is associated with upward motion of the air.

(d) **relative vorticity**—vorticity of the air relative to the Earth, disregarding the component of vorticity resulting from Earth's rotation.

W

wave turbulence—turbulence found to the rear of a solid body in motion relative to a fluid. In aviation terminology, the turbulence caused by a moving aircraft.

wall cloud—The well-defined bank of vertically developed clouds having a wall-like appearance which form the outer boundary of the eye of a well-developed tropical cyclone.

warm front—Any non-occluded, front which moves in such a way that warmer air replaces colder air.

warm sector—The area covered by warm air at the surface and bounded by the warm front and cold front of a wave cyclone.

water equivalent—The depth of water that would result from the melting of snow or ice.

water pout—See tornado.

water vapor—Water in the invisible gaseous form.

wave cyclone—A cyclone which forms and moves along a front. The circulation about the cyclone center tends to produce a wavelike deformation of the front.

weather—The state of the atmosphere, mainly with respect to its effects on life and human activity; refers to instantaneous conditions or short term changes as opposed to climate.

weather radar—Radar specifically designed for observing weather. See cloud detection radar and storm detection radar.

weather vane—A wind vane.

wedge—Same as ridge.

wet bulb—Contraction of either wet-bulb temperature or wetbulb thermometer.

wet-bulb temperature—The lowest temperature that can be obtained on a wet-bulb thermometer in any given sample of air, by evaporation of water (or ice) from the muslin wick; used in computing dew point and relative humidity.

wet-bulb thermometer—A thermometer with a muslin-covered bulb used to measure wet-bulb temperature.

whirlwind—A small, rotating column of air; may be visible as a dust devil.

willy-willy—A tropical cyclone of hurricane strength near Australia.

wind—Air in motion relative to the surface of the earth; generally wed to denote horizontal movement.

wind direction—The direction from which wind is blowing.

wind speed—Rate of wind movement in distance per unit time.

wind vane—An instrument to indicate wind direction.

wind velocity—A vector term to include both wind direction and wind speed.

wind shear—The rate of change of wind velocity (direction and/or speed) per unit distance; conventionally expressed as vertical or horizontal wind shear.

Z

zonal wind—A west wind; the westerly component of a wind. Conventionally used to describe large-scale flow that is neither cyclonic nor anticyclonic.

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